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PROP-FAN DATA SUPPORT STUDY

TECHNICAL REPORT

FEBRUARY 28, 1978

PREPARED UNDER CONTRACT NO. NAS2-9750

BY

HAMILTON STANDARD
DIVISION OF UNITED TECHNOLOGIES CORPORATION
WINDSOR LOCKS, CONNECTICUT

FOR

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

This report presents updated parametric Prop-Fan data packages and the rationale used in developing the new Prop-Fan data. These data represent Hamilton Standard's projections of Prop-Fan characteristics for aircraft that are expected to be in-service in the 1985 to 1990 time frame.

The basic Prop-Fan configuration is designed for efficient cruise operation at 0.8 Mach number and 10,668M (35,000 ft) altitude. The design blade tip speed is 244 mps (800 fps) and the design power loading is 301KW/$_{M}2$ (37.5 SHP/$_{diameter}$2).

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INTRODUCTION AND SUMMARY

The Prop-Fan propulsion concept offers the potential for a significant increase in fuel efficiency for future transport aircraft. This report was prepared to ensure that the technical information generated from recent wind tunnel and anechoic chamber tests conducted by Hamilton Standard, and the latest Prop-Fan designs performed by Hamilton Standard, will provide the data required to support NASA's on-going contracted studies.

The report provides updated parameteric Prop-Fan data packages and the rationale used in developing the new Prop-Fan data. The data respresents Hamilton Standard's projection of Prop-Fan characteristics for aircraft that are expected to be in-service in the 1985 to 1990 time frame.

The basic Prop-Fan configuration is designed for efficient operation at 0.8 Mach number and 35,000 feet (10,668 M) altitude. The design blade tip speed is 800 feet per second (244 mps) and the design power loading is 37.5 $shp/_{D}2$ (301 $KW/_{M}2$) for maximum climb power at 0.8 Mach and 35,000 feet (10,668M).

All of the new data are founded on this basic design configuration. Recent studies on advanced transport Prop-Fan configurations designed for cruise operation at other than 0.8 Mach number but between 0.7 to 0.85 Mach number indicate that the 0.8 Mach baseline provides near optimum level of aerodynamic and acoustic performance. Hence the data presented here are optimized for an 0.8 Mach configuration and are also representative of Prop-Fan performance characteristics for advanced transports at design points both below and above 0.8 Mach number.

The new data packages are enclosed as Attachments SP 13A77 through SP16A77, SP18A77 through SP20A77 and SP03A78. The discussions that follow include a description of the new data and the manner in which they were generated.

AERODYNAMIC PERFORMANCE

Recent design trends in near-field source noise reduction and increased efficiency have resulted in an eight blade Prop-Fan configuration that has more sweep and activity factor per blade than its predecessor (Model SR-1). The ten blade Prop-Fan configuration was developed because of its improved noise, efficiency, and weight characteristics, but it retains the same total rotor activity factor as the eight blade Prop-Fan.

The performance data shown in Attachments SP13A77 and SP14A77 have been updated to reflect 1) the latest performance level estimates for eight and ten blade Prop-Fans, 2) data at additional Mach numbers, and 3) Prop-Fan slipstream characteristics. This information provides a means to establish the aerodynamic efficiencies and slipstream characteristics for eight and ten blade Prop-Fans from static operation through operation at 0.80 Mach number. The data are shown in the traditional nondimensional coefficient format, i.e., net thrust coefficient ($C_{T_{Net}}$) as a function of power coefficient (C_P) for constant values of advance ratio (J). The tabular form is provided to ease computer application.

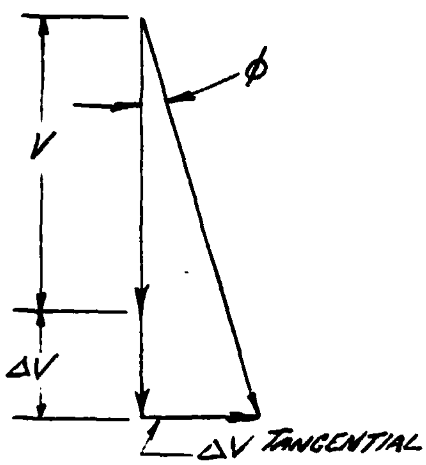
Performance tables are provided for Mach numbers ranging from 0.55 through 0.80 in increments of 0.05 Mach number plus an additional table for operation below 0.55 and static performance. Although the 0.55 to 0.80 Mach number tables include a tabulation of net efficiency (η_{Net}), the user is urged to employ the net thrust coefficient ($C_{T_{Net}}$) for computer inputs to simplify the interpolation processes.

The performance data contained in the packages were generated through Hamilton Standard's performance program H444. The projected efficiency levels that form the basis of the data packages were developed from the wind tunnel test results on the SR-1 and SR-2 Prop-Fan models, from the predicted performance of recently designed Prop-Fan models incorporating an advanced plan form shape and from the projected benefits of using advanced airfoil sections.

A simplified method developed by the Boeing Company for calculating slipstream characteristics revealed good correlation with a more sophisticated Hamilton Standard method and with the swirl data developed during Prop-Fan model wind tunnel testing. The simplified method (based on the ideal propeller characteristics method presented in Volume 4, Division L of "Airplane Propellers" by H. Glavert in the Durand "Aerodynamic Theory" series) estimates swirl angle and axial slipstream velocity distribution as a function of blade nondimensional radius. From this information and the predicted performance shown in the tables, the average swirl angle ($\emptyset$) and the average axial induced velocity immediately behind the Prop-Fan rotor, in terms of $\Delta V/V$, have been derived. The results suggest that the number of blades and Mach number are second order effects. Accordingly, the slipstream characteristics are tabulated only as a function of power coefficient (C_P) for specific values of advance ratio (J).

AERODYNAMIC PERFORMANCE (Continued)

Sample problems in both English and SI units are provided with both performance data packages.



Slipstream Characteristics

FAR- AND NEAR-FIELD NOISE

Far-field noise generalizations are presented for six, eight, and ten bladed Prop-Fans. The data allows the user to predict perceived noise levels and effective perceived noise levels during take-off and landing. The effective perceived noise level is a particularly valuable parameter since this is the measure used to establish Noise Certification Limits and to assess potential aircraft annoyance factors in areas adjacent to airports.

The far-field noise prediction procedure employed herein has been developed by Hamilton Standard for propeller noise predictions during the past ten years. It has been adopted by the Society of Automotive Engineers as an Aerospace Information Report (AIR 1407) and found to yield predictions generally within 3 PNdb of measured propeller noise levels. The reliability of the far-field method is enhanced by the good correlation obtained between actual Prop-Fan model test data and predictions derived using the Prop-Fan far-field method.

The near-field noise generalization provides fairly extensive detail for six, eight, and ten bladed Prop-Fan configurations. The procedure includes the influences of altitude, fan tip to fuselage spacing, and directivity. The directivity information is useful in establishing the amount of fuselage treatment needed to provide uniform interior cabin noise levels near the plane of rotation where the directivity is seen to peak.

The influence of spacing between the Prop-Fan tip and the fuselage on noise levels is helpful in assessing the trade-off between fuselage acoustic treatment weight and aircraft structure and control surface weights (i.e., moving the nacelle out on the wing reduces noise and treatment weight but may require an increase in tail size to meet aircraft control requirements or a wing weight change for structural reasons).

The near-field noise prediction method is based on the theoretical Prop-Fan prediction procedure developed by Hamilton Standard. Computer results have been generalized to indicate the level of noise expected for a fully developed Prop-Fan. Tests are currently under way to confirm the accuracy of the theoretical prediction procedure.

The Prop-Fan gearbox noise generalization provides estimates of the uninstalled (i.e., without additional attenuation from enclosing nacelles) gearbox noise associated with a Prop-Fan propulsion system. The prediction method is derived from a procedure developed by Hamilton Standard and published in FAA report FAA-RD-76-49, II, entitled V/STOL Rotary Propulsion Systems Noise Prediction and Reduction. The absolute accuracy of the method has not been established by correlation studies with test data since there is little test data available on installed gearboxes. However, the method should be adequate for preliminary design studies of Prop-Fan systems.

FAR- AND NEAR-FIELD NOISE (Continued)

It should be noted that the near-field gearbox noise in cruise is not expected to be significant since fuselage sidewall attentuation is large at frequencies where gearbox noise predominates. Moreover, during takeoff and landing, gearbox noise is generally well below that of the engine and Prop-Fan and should not significantly contribute to perceived noise. Accordingly, the gearbox noise prediction method is presented here to help complete the noise estimates for a Prop-Fan propulsion system.

WEIGHTS

The weight information contained in the SP18A77 and SP19A77 packages is provided to help the airframe designer in formulating aircraft weights for preliminary design studies. The curves show weight estimates for eight and ten blade Prop-Fan installations (i.e., high-speed rotor and gearbox systems) designed for 0.80 Mach number cruise aircraft. The technology level employed is appropriate for a Prop-Fan system expected to be in-service in the 1985 to 1990 time period.

The power loading (SHP/D^2) term used on the rotor weight curve in Figure 1 of the packages, is based on the maximum power delivered to the rotor. This usually occurs during the takeoff roll. The tip speed (TS) that should be used for rotor weights is that at which the maximum power occurs. The weight curve in Figure 1 is plotted for a tip speed of 800 ft/sec (244 m/sec). Rotor weights for other tip speeds can be obtained by utilizing the conversion formula provided in the curve notes. Figure 2 shows a curve of gearbox weight as a function of the maximum delivered output torque. The curve is based on a total gear ratio of 8:1. Gearbox weights for other gear ratios can be obtained from the conversion formula provided on the curve.

The data provides uninstalled rotor and gearbox weight estimates, including the major components defined on the curves. The weight of a fully installed Prop-Fan propulsion system is estimated to be 1.3 times the sum of the rotor, gearbox and engine weight. This factor is based on a turboshaft engine weight of 0.167 pounds per SHP (0.101 kg per KW) and the additional weight contributed by the following components:

- Nacelle cowling and fairings
- Nacelle structure for attachment to wing
- Engine-to-gearbox coupling structure and shaft
- Engine/gearbox mounting to nacelle structure
- Engine air inlet ducting
- Engine exhaust system
- Fire control system
- Gearbox cooling and oil tankage system
- Engine starting system
- Hydraulic system and hydraulic fluid
- Electrical system
- Fuel system
- Pneumatic system
- Engine and Prop-Fan control linkage.

WEIGHTS (Continued)

The weight projection in the two data packages presented here are a result of the latest Prop-Fan technology development work. Two specific technology areas have contributed significantly to this work. First, the rotor weights take into account the projected blade planform shapes from recent aerodynamic and acoustic design work; second, the rotor weights reflect the results of a recently completed reliability and maintenance study. The reliability and maintenance cost efforts were completed under NASA contract NAS3-20057 and will be published as NASA CR135192. The study report is entitled "Study of Turboprop Systems Reliability and Maintenance Costs.

During the R&MC study, a 12.8 foot (3.9m) diameter point design Prop-Fan with eight blades was concepted. The weights of all parts were estimated and it is these weights which form the basis for the parametric data being discussed here. These estimated weights were ratioed using mathematical relationships proven by past propeller experience to provide rotor weights for the diameter range of 10 to 20 feet (3.05 to 6.1m) and power loading range of 15 to 80 SHP/D^2 shown in the parametric data. The rotor concept includes several features which were designed to improve reliability and ease maintenance but which increased the rotor weight. Among these are separate blade retention bearing races and a bolted rotor mounting flange. A rotor weight increase was also incurred due to the increased blade chord width associated with improved performance in the eight blade rotors. This weight increase is also reflected in the ten blade rotor which has the same total rotor solidity as the eight blade rotor. The ten blade rotor is significantly lighter than the eight blade rotor for the same diameter and power loading. This is because the total blade solidity is comprised of more but narrower airfoils in the ten blade rotor resulting in lower total blade weight, loads and twisting moments.

The gearbox weight curve in Figure 2 shows a linear relationship of weight with output torque. This is based on past parametric studies in addition to the preliminary design work accomplished during the turboprop reliability and maintainability study. The weights are based on a dual compound idler gearbox concept with a high bearing set B10 life. Both of these gearbox design features were incorporated to improve reliability and reduce maintenance costs.

INSTALLATION GUIDELINES

Previous studies have shown that the selection of the optimum Prop-Fan configuration and power loading must include an assessment of Prop-Fan diameter and its impact on the aircraft design. It is recommended, therefore, that these guidelines be used in the general parametric and preliminary design studies for Prop-Fan propulsion systems.

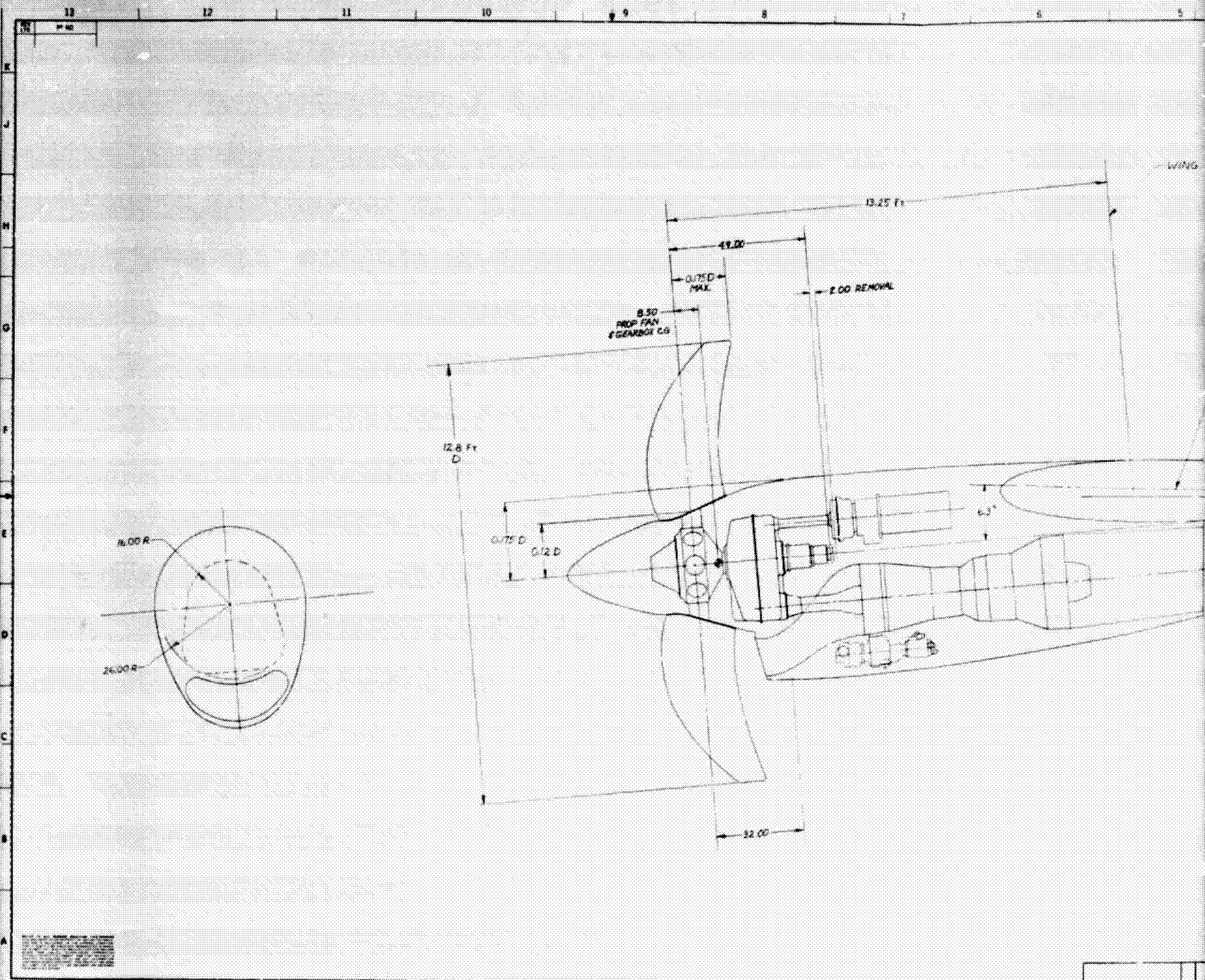
A typical Prop-Fan nacelle arrangement is shown in Hamilton Standard drawing SK 93074. This drawing reflects an updated version of the 12.8 foot (3.9m) diameter, eight blade point design Prop-Fan studied under NASA contract NAS 3-20057. An Allison PD 370-22 engine is shown driving the Prop-Fan with blades of advanced design through a dual compound idler gearbox. Aircraft accessories are driven from a pad on the upper rear of the gearbox. The Prop-Fan pitch change regulator and slip ring assembly are both mounted at the center rear of the gearbox with quick disconnects to ease maintenance. Based on discussions with engine and airframe manufacturers, an engine inlet duct with a 10% area reduction from inlet to engine compressor face is shown. Nacelle axisymmetric radius and length were obtained from attachment SP20A77.

Formulas for Nacelle Placement

The Prop-Fan spacing requirements on the wing for a four engine aircraft, shown in Figure 1 of attachment SP20A77, are governed by three factors: 1) erosion and impact effects on the blades, 2) excitation of blades during ground operation, and 3) cabin noise. The first factor defines the recommended blade-to-ground clearance, H; the second defines the separation of adjacent Prop-Fans, T; and the third defines the separation of the inboard Prop-Fan from the fuselage, F. Excitation of the blades is also influenced by "F" but at the recommended separation the noise requirement is the controlling factor.

The recommended ground clearance to assure low blade impact and erosion rates from foreign objects is proportional to the aircraft size, takeoff and landing distance, the suction action of the Prop-Fan, and the flight frequency. The takeoff and landing distances are directly proportional to wing loading or cruise Mach number and inversely proportional to the thrust. The suction factor is proportional to the disc loading, or thrust divided by the square of the Prop-Fan diameter. Thus, the required ground clearance is proportional to the aircraft gross weight and cruise Mach number divided by the square of the Prop-Fan diameter assuming a given takeoff and landing distance and flight frequency.

FOLDOUT FRAME 1



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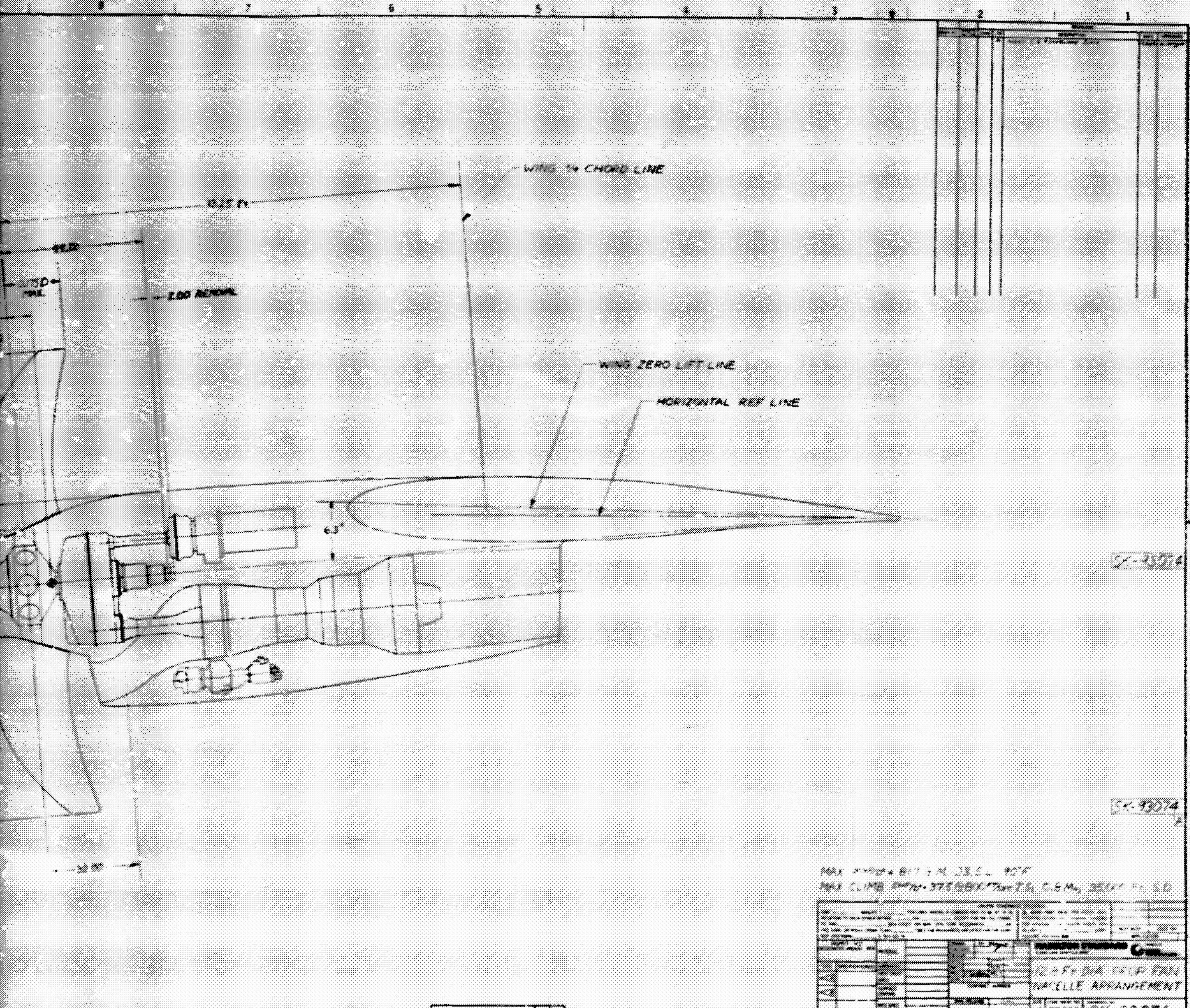
FOLDOUT FRAME 2



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INSTALLATION GUIDELINES (Continued)

The recommended separation of adjacent Prop-Fans, T, is defined so that the slipstream of the outboard Prop-Fan does not interfere with the inboard Prop-Fan or vice versa. This is a geometric problem involving the wing sweep, which increases the required separation. The formula is based on a minimum clearance of flow fields of 5% of the Prop-Fan diameter in order to assure low excitations during ground running operations.

It is desirable to locate the Prop-Fan a large distance, F, from the fuselage to minimize cabin noise. However, trade-off studies of wing structural weight and tail surface area versus cabin acoustic treatment weight, must be conducted for individual aircraft design to determine the optimum Prop-Fan placement. A recommended value of F equal to (0.8) D is based on several studies of this nature. A minimum value of F equal to (0.2) D is required to maintain blade excitation loads within acceptable limits. The noise levels at the fuselage for values of F between (0.2) D and (1.6) D are presented in the near-field noise data package in attachment SP15A77.

Definition of Nacelle Configuration

The Prop-Fan nacelle configuration in Figure 2 is determined primarily by two factors: performance and aerodynamic blade excitations. The former dictates the required axisymmetric diameter, d, of the nacelle as a function of power loading SHP/D^2. The dashed line represents the more realistic configuration needed for handling the engine inlet. Figure 3 shows the required ratio of nacelle diameter to Prop-Fan diameter for the 8 and 10 blade Prop-Fans of equal total activity factor based on reducing the velocity at the plane of the blades to alleviate compressibility losses and blade root choking. The six blade configuration with the same activity factor per blade as the eight blade, has less root choking and, therefore, permits a smaller nacelle diameter. Since the effects of nacelle diameter on performance have not been sufficiently analyzed at the higher power loadings, the diameter ratios in Figure 3 were cut off at a reasonable level.

The basic structural capacity requirements of the blades and hub are dictated primarily by the aerodynamic excitation loads and blade response of the Prop-Fan. The blade excitations are functions of the angularity and velocity variation in the flow field at the plane of the Prop-Fan. These are usually expressed in terms of Excitation Factor, $EF = \psi e\ (V/348)^2$, where ψe is the equivalent angular inflow at the plane of the Prop-Fan and V^2 is proportional to the dynamic pressure. The equivalent angular inflow, ψe, is dependent on several factors: the distance, L, the plane of the Prop-Fan is from the quarter chord of the wing; the tilt angle, ψt, of the Prop-Fan thrust axis, or nacelle, with respect to the zero lift line of the wing; the strength of the wing circulation or wing loading; the attitude of the aircraft and the variation in the flow field due to the sweep of the wing. By optimizing the nacelle tilt, ψt, the

INSTALLATION GUIDELINES (Continued)

excitations during cruise are usually minimized and the excitations during climb are significantly decreased. Usually, the maximum climb condition determines the design excitations and loads on the blades. Parametric analysis shows that the blade moment and shear loads are proportional to D^3 and D^2, respectively, so that the respective steady-shaft loads, M and V, are proportional to D^3 and D^2 times the number of blades. For convenience, the equations for M and V in Figure 4 have the number of blades and the effect of blade activity factor included in the constants. The curve of nacelle length versus Prop-Fan diameter in Figure 4 is based on an equivalent excitation factor of 5 which includes both first order and higher order excitations. The greater nacelle lengths are necessary for higher Mach number operation because the increasing wing sweep with Mach number increases significantly the higher order blade aerodynamic excitations. The steady-shaft load, M and V, are functions only of the first order (once-per-revolution) aerodynamic loads. Therefore, these loads decrease with Mach number because of the greater percentage of higher order excitation in the equivalent excitation factor of 5.

Wing/Nacelle Stiffness Required to Prevent Whirl Flutter

Figure 5 is a schematic diagram of a Prop-Fan with diameter, D, mounted distance, ℓ, from the effective torsional center of the wing/nacelle mounting system with a torsional stiffnes, K_T.

Figure 6 shows how the minimum required K_T to prevent whirl flutter varies with the ratio D/ℓ at several Prop-Fan diameters.

The minimum effective torsional stiffness requirements are based on a simple Houbolt whirl flutter analysis using propeller derivatives based on our aerodynamic performance results. The trends follow those in Houbolt's & Reed's IAS paper 61-34, "Propeller-Nacelle Whirl Flutter." As diameter increases, the Prop-Fan mass and moment of inertia increase, thereby requiring greater effective torsional stiffness to assure stability from whirl flutter. The aerodynamic derivatives increase with flight speed, so that more stiffness is required at higher Mach numbers. As the ratio D/ℓ increases, the required stiffness increases because aerodynamic damping, (i.e., stabilizing forces times pivot length) decreases.

INSTALLATION GUIDELINES (Continued)

Sensitivity Requirements for Passenger Comfort

The aircraft sensitivity requirements for passenger comfort are a function of two factors: the vibration level requirements for passenger comfort and the once-per-revolution excitation due to Prop-Fan unbalance. An acceptable overall cabin vibration level is dependent on the statistical sum of the excitations transmitted from th- inboard and outboard Prop-Fans. This relationship is shown in attachment SP20A77. The cabin comfort vibration limit is based on the information given in the March, 1965 issue of "Mechanical Engineering" which shows that the imperceptible level is inversely proportional to the 1.15 power of the frequency and, therefore, directly proportional to the 1.15 power of the Prop-Fan diameter for a constant tip speed. A parametric statistical unbalance analysis conducted by Hamilton Standard shows that Prop-Fan unbalance is caused by both aerodynamic and mass unbalance effects which are proportional to the square of the Prop-Fan diameter for a given tip speed and to the square root of the number of blades. The allowable unbalance then is inversley proportional to the diameter squared and the square root of the number of blades. Combining the above two factors of permissible unbalance and vibration levels, leads to the relationship on the last page in attachment SP20A77. The absolute value of Prop-Fan unbalance was scaled based on the DHC-7 propeller unbalance, which has resulted in imperceptible cabin vibration.

RELIABILITY AND MAINTENANCE

A data package has been prepared that contains the following reliability and maintainability information for a range of sizes of Prop-Fan and reduction gearboxes:

. Removal rates

. Direct maintenance man hours per flight hour and parts cost per flight hour.

Several assumptions and conditions were made in estimating the reliability and maintainability values presented in the data packages:

. Blade tip-to-ground clearance is per H of Figure 1, SP20A77.

. A duty cycle of 1.25 hours per flight was assumed.

. A commercial operating environment with average monthly aircraft utilization of 250 hours was assumed.

. A commercial on-condition maintenance philosophy was assumed.

The R&M data was generated based on NASA-funded work performed by Hamilton Standard and to be reported in NASA CR-135192. In that program, a detailed reliability and maintenance cost study was performed of the Prop-Fan configuration as proposed for use in a commercial environment. The study focused on the following Prop Fan and gearbox items:

Prop Fan

o Spinner
o Disc & Aft Fairing
o Forward Cover & Fairing
o Blades
o Pitch Change Actuator
o Pitch Change Regulator
o Slip Ring Assembly
o De-icing Conduit Assembly
o Transfer Tube Assembly
o Variable Delivery Pump
o Auxiliary Pump & Filter

Mounted on gearbox at Hydraulic pump drive.

Gearbox

o Gearbox Housing
o Main Reduction Gear Train
o Accessory Drive Gear
o Power-take-off Drive Gear
o Prop Brake & Hydraulic Pump Drive Gear
o Lube Oil Pump Drive Gear

The basic data contained in the referenced report was generated based on analysis of the Prop-Fan configuration design and preliminary parts list. Specific techniques utilized can be summarized as follows:

- A piece-part reliability prediction was performed. The primary data source was Hamilton Standard's experience with the 54H60-77 propeller used on the P-3 aircraft. Other data sources included vendor data and Government Industry Data Exchanger Program (GIDEP).

- Average repair times, which are needed to develop maintenance man-hour per flight-hour estimates, were developed by Hamilton Standard personnel from the Overhaul and Repair Department who are skilled in estimating repair times under competitive conditions. Results were compared with, and validated against, records of actual repair times for similar equipment.

- Parts cost per repair were developed based on historical records for similar hardware from which repair costs as a percentage of acquisition cost were established. These percentages, adjusted to reflect the on-condition maintenance philosophy, were applied to the Prop-Fan acquisition costs and, in turn, the parts cost per flight hour estimates were determined based on removal/repair rates.

COSTS

In this section cost estimates for a Prop-Fan propulsion system are provided. The cost estimates contained herein are budgetary, 1977 economy, and intended for study purposes only.

The Prop-Fan system is envisioned to include the rotor assembly (blades, disc, pitch-change actuator, and spinner), a pitch change regulator, a slip ring, and an integrated gearbox unit (gearing, housings,lube system). The costs for this program were estimated on the basis of similar programs conducted recently. The hardware costs were estimated by breaking the system into major components and comparing these components to similar propeller components currently in production for aircraft such as the Navy E2, C2 and P-3. Factors were then applied to account for differences in size, simplicity, materials, etc.

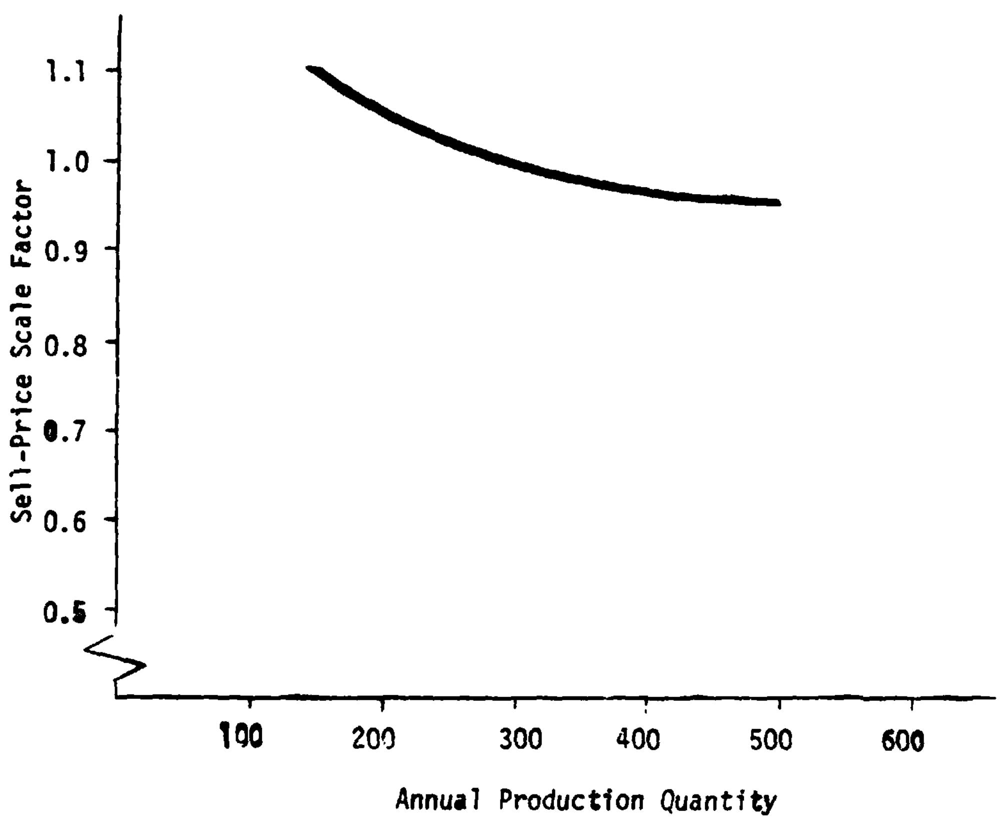
Cost information for two configurations (eight and ten bladed Prop-Fans) and two different diameters, are provided in the summary below. For study purposes, it is recommended that a linear relationship between cost and diameter be maintained for the range under consideration. The factors used to develop the cost relationships include Prop-Fan diameter, activity factor, weight, and power loading. As previously described in the technical summary, the ten-way Prop-Fan has the same total rotor activity factor as the eight-way configuration. This approach results in a blade that is approximately 20% narrower and, in spite of the addition of two blades, yields a slightly lighter rotor in the ten-way configuration than in the eight-way.

COST SUMMARY
(1977 ECONOMY)

Prop-Fan Diameter	13 Feet (3.96M)		16 Feet (4.88M)	
Number of blades	8	10	8	10
Delivery Production Units (Price per each Prop-Fan)	$227K	$227K	$284K	$284K

The prices for production units are based on delivery rates of 300 units per year. For other production rates, the price-quantity scale factor should be applied to adjust the unit sell price.

PRICE VERSUS QUANTITY SCALE FACTOR



HAMILTON STANDARD

SP13A77
Revision A
2/28/78

PROP-FAN PERFORMANCE ESTIMATION
FOR THE
EIGHT (8) BLADE PROP-FAN CONFIGURATION

October 31, 1977

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

PROP-FAN PERFORMANCE ESTIMATION

This data package provides Prop-Fan Performance in a non-dimensional coefficient format which permits the user to estimate performance over a broad range of operating conditions. The data is presented in tabular form for ease of computer application.

The performance is presented in terms of net thrust coefficient ($C_{T_{Net}}$) as a function of power coefficient (C_p) for constant values of advance ratio (J). The following tables are included:

I	Mach Number	<.55
II	Mach Number	=0.55
III	Mach Number	=0.60
IV	Mach Number	=0.65
V	Mach Number	=0.70
VI	Mach Number	=0.75
VII	Mach Number	=0.80
VIII	Slipstream Characteristics	

The 0.55 to 0.80 Mach number tables also include a tabulation of net efficiency (η_{Net}) to allow for a visual estimation of performance level.

The non-dimensional coefficients are defined in engineering terms as English Units:

$$J = \frac{101.4\ M_o\ C_K}{ND} = \frac{101.4\ V}{ND}$$

$$C_p = \frac{SHP\ (\rho o/\rho)}{20\ (ND/10{,}000)^3\ D^2} = \frac{SHP\ (\rho o/\rho)}{2000\ (N/1000)^3\ (D/10)^5}$$

$$T_{NET} = 66.1\ (ND/10{,}000)^2\ D^2\ C_{T_{NET}}/(\rho o/\rho)$$

$$T_{NET} = 6610\ (N/1000)^2\ (D/10)^4\ C_{T_{NET}}/(\rho o/\rho)$$

where: T_{NET} = Uninstalled Prop-Fan net thrust, pounds

N = Prop-Fan rotational speed, rpm

D = Prop-Fan tip diameter, feet

ρ_o/ρ = Density ratio, sea level ISA to ambient conditions (ρo=0.002378 lb-sec^2/ft^4)

M_o = Free stream Mach number

C_K = Speed of sound, knots

V = Free stream velocity, true airspeed, knots

where: ND = (TS) (60)/π

TS = Tip speed ft per second

ϕ = Average swirl angle, degrees

ΔV = Incremental induced axial velocity immediately behind disk, knots

In SI Units:

$$J = \frac{60\ M_o\ C_{m/s}}{ND} = \frac{60\ V}{ND}$$

$$C_p = \frac{KW\ (\rho_o/\rho)}{5.674\left(\frac{ND}{1000}\right)^3 D^2}$$

$$T_{NET} = 3409.2\left(\frac{ND}{1000}\right)^2 D^2\ C_{T_{NET}} / \ (\rho_o/\rho)$$

where K_W = power, kilowatts

T_{NET} = Uninstalled Prop-Fan net thrust, newtons

N = Prop-Fan Rotational Speed, RPM

D = Prop-Fan Diameter, Meters

ρ_o/ρ = Density ratio, sea level ISA to ambient conditions

M_o = Free stream Mach number

$C_{m/s}$ = Speed of sound, meters per second

V = Free stream velocity, meters per second

ϕ = Average swirl angle degrees

ΔV = Incremental axial induced velocity immediately behind disk, meters per second

where $ND = (TS)\ (60)\ /\ \pi$

TS = tip speed, meters per second

The "Net Thrust (T_{NET})" is the uninstalled thrust of the Prop-Fan rotor operating in the presence of a nacelle. The buoyancy force between the rotor and nacelle face has been removed from the rotor thrust, and therefore it should not be included in the nacelle drag. Installed propulsive thrust is obtained by adding the uninstalled net thrust (T_{NET}) to the core engine jet thrust and then subtracting the drag of the nacelle and the losses due to nacelle/wing interference.

The slipstream characteristics are also presented in tabular form. Average swirl angle (ϕ) and incremental axial induced velocity immediately behind the disk over freestream velocity ($\Delta V/V$) are presented as a function of power coefficient (C_p) for given values of advance ratio (J). Theoretically the induced axial velocity doubles in the ultimate wake which is approximately two diameters downstream.

SAMPLE PROBLEMS

English Units

Given: 5322 lb installed thrust required at 0.80 Mach number at 35,000 ft., ISA

Select the diameter required for an:

SHP/D^2 of 37.5 for an 8 bladed Prop-Fan operating at 800 feet per second tip speed

Calculate: $ND = (800)\ (60)\ /\ \pi = 15{,}279$

$$C_P = \frac{(SHP/D^2)\ (\rho o/\rho)}{20\ (ND/10{,}000)^3} =$$

$$= \frac{(37.5)\ (3.2196)}{(20)\ (1.5279)^3}$$

$$= 1.692$$

$$J = (101.4)\ (Mo)(C_K)/ND$$

$$= (101.4)\ (0.80)(576.3)/15279$$

$$= 3.060$$

$$C_{T_{NET}} = 0.4505 \text{ (Table VII)}$$

$$\eta_{NET} = \frac{C_{T_{NET}}}{C_P}\ J = \frac{(0.4505)(3.060)}{1.692} = 0.815$$

and $T_{NET} = 66.1\ (D)^2\ (ND/10{,}000)^2\ C_{T_{NET}}/\ (\rho o/\rho)$

$$= 66.1\ (D)^2\ (1.5279)^2\ (0.4505)/\ (3.2196)$$

$$= 21.592\ D^2$$

For the engine selected, calculate a diameter such that:

Net Thrust + Jet Thrust - Nacelle Drag - Wing Int. Drag = 5322 lbs

This is an iterative process.

For example:

Diameter	= 15.56 feet
T_{Net}	= 5228 pounds
T_{jet}	= +408 pounds
$D_{Nacelle}$	= −209 pounds
D_{interf}	= −105 pounds
$T_{installed}$	= 5322 pounds

$SHP = (SHP/D^2)(D^2) = (37.5)\ (15.58)^2 = 9079$

For take-off, climb loiter and other performance points for Mach numbers less than 0.55 utilize table I which covers the low J advance ratio range of operation.

For example, for the 8/15.56 foot diameter Prop-Fan, calculate the power required for a net thrust of 20241 pounds at 0.25 Mach number at sea level, ISA

Calculate: −

$$J = (101.4)\ (Mo)\ (C_K)\ /\ ND$$

$$= (101.4)\ (0.25)\ (661.2)\ /\ 15279$$

$$= 1.097$$

$$C_{T_{Net}} = (T_{Net})\ (\sigma_0/\sigma)\ /\ 66.1\ (ND/10000)^2\ D^2$$

$$= (20241)\ (1.0)\ /\ 66.1\ (1.5279)^2\ (15.56)^2$$

$$= 0.542$$

From Table I $C_p = 0.984$

$$SHP = (20)\ (ND/10000)^3\ D^2\ C_p\ /\ (\sigma_0/\sigma)$$

$$= (20)\ (1.5279)^3\ (15.56)^2\ (0.984)\ \ 1.0$$

$$= 17000$$

SI Units

Given: 23,672 Newtons of installed thrust at 0.80 Mach number of 10,668 meters ISA altitude

Select the diameter required for a:

$KW/D^2 = 301\ KW/M^2$ for an 8 bladed Prop-Fan operating at 243.84 mps tip speed

Calculate: $ND = (243.84)\ (60)\ /\ \pi = 4657$

$$C_p = \frac{(KW/D^2)\ (\rho o/\rho)}{5.674\ \left(\frac{ND}{1000}\right)^3}$$

$$= \frac{(301)\ (3.2196)}{(5.674)\ (4.657)^3}$$

$$= 1.691$$

$$J = \frac{(60)\ (Mo)\ (C_{m/s})}{ND} =$$

$$= \frac{(60)\ (0.8)\ (296.48)}{4657} = 3.06$$

$$C_{T_{Net}} = .4505 \text{ (Table VII)}$$

$$\eta_{Net} = \frac{C_{T_{Net}}}{C_p} J = \frac{(0.4505)\ (3.06)}{1.691} = 0.815$$

and $$T_{NET} = 340.42 \left(\frac{ND}{1000}\right)^2 D^2\ C_{T_{Net}}\ /\ (\rho o/\rho)$$

$$= 340.42\ (4.657)^2\ D^2\ (0.4505)\ /\ 3.2196$$

$$T_{NET} = 1033.7\ D^2$$

For the engine selected, calculate a diameter such that:

Net Thrust + Jet Thrust - Nacelle Drag - Wing Int. Drag = 23672 Newtons

This is an iterative process.

For example:

Diameter	= 4.743 meters
T_{net}	= 23254 newtons
T_{jet}	= +1815 newtons
$D_{nacelle}$	= -930 newtons
D_{interf}	= -467 newtons
$T_{installed}$	= 22672 newtons

$KW = (KW/D^2)\ (D^2) = (301)\ (4.743)^2 = 6771$

For takeoff, climb, loiter and other performance points for Mach numbers less than 0.55, utilize table I which covers the low advance ratio range of operation.

For example, for the 8 blade, 4.743 meter diameter Prop-Fan, calculate the power required for a net thrust of 90032 newtons at 0.25 Mach number at Sea Level, ISA at 243.84 meters per second tip speed

Calculate: - $J = (60)\ (Mo)\ (Cm/s)\ /ND$

$= (60)\ (0.25)\ (340.2)\ /\ 4657$

$= 1.096$

$C_{TNet} = (T_{Net})\ (\rho o/\rho)\ /\ 340.42\ (ND/1000)^2\ D^2$

$= (90032)\ (1.0)\ /\ 340.42\ (4657)^2\ (4743)^2$

$= 0.542$

From Table I $C_p = 0.984$

$KW = 5.674\ (ND/1000)^3\ D^2\ C_p\ /\ (\rho o/\rho)$

$= 5.674\ (4.657)^3\ (4.743)^2\ (0.984)\ /\ (1.0)$

$= 12686$

TABLE I

5 BLADED PROP-FAN PERFORMANCE

<0.55 MACH NUMBER

J	C_p	$C_{T_{Net}}$	J	C_p	$C_{T_{Net}}$	J	C_p	$C_{T_{Net}}$
0	0.1074	0.2064	0.6	0.0629	0.0659	1.2	0.1008	0.0640
	0.1519	0.2674		0.1210	0.1392		0.2367	0.1623
	0.2070	0.3280		0.1952	0.2164		0.3890	0.2573
	0.2714	0.3851		0.2841	0.2944		0.5538	0.3476
	0.3420	0.4361		0.3856	0.3710		0.7320	0.4312
	0.4196	0.4799		0.5007	0.4444		0.9306	0.5062
	0.5037	0.5142		0.6333	0.5127		1.1475	0.5694
	0.5935	0.5385		0.7846	0.5740		1.3765	0.6226
	0.6848	0.5524		0.9473	0.6219		1.6139	0.6611
	0.7675	0.5559		1.1195	0.6551		1.8098	0.6779
	0.8478	0.5561		1.2976	0.6872		2.0049	0.6855
	0.9137	0.5403		1.4871	0.7221			
	0.9686	0.5185		1.6682	0.7373	1.4	0.0448	0.0137
	0.9983	0.4870					0.2037	0.1204
	1.0218	0.4499	0.8	0.0926	0.0857		0.3790	0.2235
				0.1784	0.1687		0.5684	0.3202
0.2	0.1000	0.1655		0.2794	0.2520		0.7695	0.4099
	0.2000	0.2905		0.3949	0.3337		0.9908	0.4904
	0.3000	0.3852		0.5230	0.4122		1.2339	0.5588
	0.4000	0.4580		0.6679	0.4850		1.4888	0.6143
	0.5000	0.5185		0.8326	0.5504		1.7511	0.6548
	0.6000	0.5660		1.0106	0.6055		2.0188	0.6760
	0.7000	0.5940		1.1969	0.6465			
	0.8000	0.6140		1.3929	0.6721	1.6	0.1684	0.0844
	0.9000	0.6250		1.5921	0.6956		0.3710	0.1957
	1.0000	0.6180		1.7551	0.7146		0.5890	0.2992
				1.9110	0.7206		0.8179	0.3949
0.4	0.0819	0.1147					1.0676	0.4815
	0.1321	0.1828	1.0	0.0466	0.0262		1.3399	0.5538
	0.1970	0.2560		0.1463	0.1167		1.6215	0.6098
	0.2758	0.3305		0.2637	0.2070		1.9123	0.6511
	0.3666	0.4038		0.3955	0.2949		2.2074	0.6719
	0.4714	0.4737		0.5399	0.3791			
	0.5936	0.5381		0.6999	0.4571	1.8	0.1371	0.0566
	0.7329	0.5904		0.8801	0.5270		0.3723	0.1757
	0.8828	0.6324		1.0749	0.5856		0.6228	0.2856
	1.0439	0.6759		1.2809	0.6343		0.8448	0.3883
	1.2055	0.7078		1.4952	0.6664		1.1639	0.4794
	1.3831	0.7420		1.7200	0.6864		1.4699	0.5542
	1.5439	0.7468		1.8058	0.6916		1.7825	0.6098
				1.9774	0.7002		2.1053	0.6501
							2.4318	0.6605

TABLE I (Cont)

8 BLADED PROP-FAN PERFORMANCE

< 0.55 MACH NUMBER

J	C_P	$C_{T_{Net}}$
2.0	0.2241	0.0903
	0.3892	0.1656
	0.5604	0.2377
	0.7361	0.3055
	0.9153	0.3698
	1.0998	0.4297
	1.2917	0.4844
	1.4934	0.5324
	1.7002	0.5722
	1.8389	0.5945
	1.9801	0.6146
2.2	0.0565	0.0045
	0.2404	0.0872
	0.4309	0.1670
	0.6270	0.2427
	0.8268	0.3133
	1.0293	0.3797
	1.2374	0.4413
	1.4534	0.4968
	1.6031	0.5295
	1.7577	0.5591
	1.9106	0.5833
	2.0655	0.6042
	2.2229	0.6235
2.4	0.1453	0.0391
	0.2874	0.0966
	0.4323	0.1527
	0.5786	0.2072
	0.7282	0.2582
	0.8785	0.3071
	1.0296	0.3542
	1.1824	0.3989
	1.3381	0.4413
	1.4975	0.4806
	1.6609	0.5165
	1.8297	0.5483
	2.1722	0.5988
2.6	0.1322	0.0283
	0.2929	0.8911
	0.4562	0.1480
	0.6211	0.2051
	0.7889	0.2586
	0.9576	0.3096
	1.1271	0.3586
	1.2982	0.4051
	1.4718	0.4488
	1.6492	0.4891
	1.8313	0.5208
	2.0189	0.5581
	2.2103	0.5858
	2.3996	0.6074
2.8	0.1461	0.0285
	0.3270	0.0921
	0.5105	0.1537
	0.6952	0.2127
	0.8832	0.2682
	1.0719	0.3210
	1.2672	0.3714
	1.4521	0.4192
	1.6459	0.4638
	1.8438	0.5045
	2.0466	0.5410
3.0	0.1944	0.0399
	0.3972	0.1059
	0.6025	0.1694
	0.8089	0.2303
	1.0187	0.2871
	1.2287	0.3410
	1.4396	0.3926
	1.6523	0.4409
	1.8683	0.4856
	2.0889	0.5259
3.2	0.0626	-.0056
	0.2854	0.0626
	0.5121	0.1304
	0.7402	0.1953
	0.9303	0.2573
	1.2035	0.3148
	1.4365	0.3696
	1.6706	0.4214
	1.9071	0.4697
	2.1479	0.5134

TABLE II

8 BLADED PROP-FAN PERFORMANCE

0.55 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.0	0.3976	0.1717	0.864
	0.5065	0.2193	0.866
	0.6187	0.2647	0.856
	0.7343	0.3087	0.841
	0.8529	0.3573	0.825
	0.9741	0.3933	0.807
	1.0979	0.4335	0.790
	1.2241	0.4724	0.772
2.2	0.4954	0.1956	0.869
	0.6198	0.2440	0.866
	0.7425	0.2902	0.854
	0.8782	0.3550	0.839
	1.0117	0.3786	0.824
	1.1479	0.4209	0.806
	1.2864	0.4614	0.789
2.4	0.3665	0.1283	0.841
	0.5017	0.1810	0.866
	0.6403	0.2321	0.870
	0.7824	0.2808	0.862
	0.9275	0.3277	0.848
	1.0755	0.3729	0.833
	1.2261	0.4172	0.816
	1.3794	0.4595	0.799
	1.5350	0.5001	0.782
2.6	0.3786	0.1204	0.827
	0.5301	0.1759	0.863
	0.6849	0.2291	0.870
	0.8433	0.2802	0.864
	1.0048	0.3290	0.851
	1.1693	0.3762	0.837
	1.3365	0.4222	0.821
	1.5063	0.4660	0.804
	1.6787	0.5079	0.787
2.8	0.2516	0.0678	0.699
	0.4172	0.1225	0.823
	0.5867	0.1802	0.860
	0.7599	0.2355	0.868
	0.9365	0.2886	0.863
	1.1163	0.3392	0.851
	1.2991	0.3881	0.837
	1.4849	0.4357	0.821
	1.6734	0.4807	0.804
	1.8648	0.5238	0.787
	2.0584	0.5652	0.770
3.0	0.3028	0.0726	0.719
	0.4883	0.1345	0.826
	0.6777	0.1940	0.859
	0.8709	0.2510	0.865
	1.0675	0.3056	0.859
	1.2674	0.3579	0.847
	1.4706	0.4082	0.833
	1.6768	0.4570	0.817
	1.8861	0.5030	0.800
	2.0979	0.5469	0.782
	2.3118	0.5899	0.766
3.2	0.3922	0.0931	0.751
	0.5994	0.1564	0.835
	0.8106	0.2171	0.857
	1.0255	0.2756	0.860
	1.2442	0.3314	0.852
	1.4662	0.3848	0.840
	1.6915	0.4364	0.826
	1.9204	0.4862	0.810
	2.1515	0.5324	0.792
	2.3848	0.5766	0.774
3.4	0.3008	0.0555	0.628
	0.5272	0.1226	0.791
	0.7581	0.1877	0.842
	0.9929	0.2493	0.854
	1.2318	0.3087	0.852
	1.4744	0.3655	0.843
	1.7204	0.4201	0.830
	1.9699	0.4726	0.816
	2.2217	0.5217	0.798
	2.4758	0.5680	0.780

TABLE III

8 BLADED PROP-FAN PERFORMANCE

0.60 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.2	0.5068	0.2001	0.869
	0.6347	0.2494	0.865
	0.7660	0.2965	0.852
	0.9005	0.3422	0.836
	1.0379	0.3868	0.820
	1.1779	0.4295	0.802
	1.3212	0.4711	0.784
	1.4659	0.5105	0.766
2.4	0.3727	0.1308	0.843
	0.5106	0.1843	0.866
	0.6522	0.2362	0.869
	0.7972	0.2855	0.860
	0.9456	0.3332	0.846
	1.0969	0.3792	0.830
	1.2508	0.4240	0.813
	1.4073	0.4666	0.796
	1.5671	0.5081	0.778
2.6	0.2343	0.0645	0.716
	0.3843	0.1225	0.829
	0.5382	0.1786	0.863
	0.6959	0.2327	0.869
	0.8571	0.2844	0.863
	1.0216	0.3339	0.850
	1.1891	0.3816	0.835
	1.3592	0.4281	0.819
	1.5323	0.4724	0.802
	1.7077	0.5147	0.784
	1.8859	0.5556	0.767
2.8	0.2545	0.0638	0.702
	0.4225	0.1243	0.824
	0.5944	0.1827	0.860
	0.7702	0.2387	0.867
	0.9495	0.2923	0.862
	1.1321	0.3435	0.850
	1.3179	0.3929	0.835
	1.5065	0.4410	0.819
	1.6981	0.4864	0.802
	1.8925	0.5298	0.784
	2.0893	0.5721	0.767
3.0	0.3061	0.0736	0.722
	0.4940	0.1362	0.827
	0.6880	0.1964	0.859
	0.8818	0.2541	0.864
	1.0812	0.3092	0.858
	1.2840	0.3620	0.846
	1.4901	0.4129	0.831
	1.6994	0.4622	0.816
	1.9120	0.5085	0.798
	2.1266	0.5526	0.780
3.2	0.3964	0.0943	0.759
	0.6061	0.1583	0.836
	0.8200	0.2196	0.857
	1.0378	0.2787	0.859
	1.2594	0.3350	0.851
	1.4846	0.3891	0.839
	1.7129	0.4411	0.824
	1.9449	0.4910	0.808
	2.1794	0.5378	0.790
	2.4158	0.5823	0.772
3.4	0.3036	0.0563	0.630
	0.5329	0.1241	0.792
	0.7664	0.1899	0.842
	1.0043	0.2521	0.854
	1.2462	0.3120	0.851
	1.4918	0.3694	0.842
	1.7410	0.4244	0.829
	1.9939	0.4773	0.814
	2.2491	0.5267	0.796
	2.5066	0.5734	0.778
3.6	0.2188	0.0238	0.3[illegible]
	0.4691	0.0950	0.72[illegible]
	0.7242	0.1643	0.817
	0.9837	0.2306	0.844
	1.2476	0.2935	0.847
	1.5154	0.3536	0.841
	1.7869	0.4115	0.830
	2.0616	0.4673	0.816
	2.3392	0.5198	0.800
	2.6193	0.5682	0.781

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TABLE IV

8 BLADED PROP-FAN PERFORMANCE

0.65 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.4	0.3822	0.1345	0.845
	0.5244	0.1894	0.867
	0.6704	0.2424	0.868
	0.8202	0.2929	0.857
	0.9733	0.3416	0.842
	1.1296	0.3888	0.826
	1.2888	0.4345	0.809
	1.4505	0.4779	0.791
	1.6147	0.5195	0.772
	1.7810	0.5605	0.756
2.6	0.2385	0.0661	0.721
	0.3919	0.1253	0.832
	0.5495	0.1825	0.863
	0.7111	0.2376	0.869
	0.8763	0.2901	0.861
	1.0450	0.3405	0.847
	1.2168	0.3892	0.832
	1.3914	0.4363	0.815
	1.5690	0.4814	0.798
	1.7488	0.5241	0.779
2.8	0.2583	0.0652	0.707
	0.4295	0.1268	0.827
	0.6049	0.1860	0.861
	0.7843	0.2429	0.867
	0.9674	0.2973	0.860
	1.1538	0.3493	0.848
	1.3435	0.3994	0.833
	1.5360	0.4479	0.816
	1.7317	0.4938	0.799
	1.9305	0.5379	0.780
3.0	0.1238	0.0102	0.246
	0.3104	0.0750	0.725
	0.5014	0.1385	0.829
	0.6968	0.1994	0.859
	0.8960	0.2580	0.864
	1.0990	0.3138	0.857
	1,3055	0.3673	0.844
	1.5154	0.4188	0.829
	1.7283	0.4685	0.813
	1.9430	0.5153	0.795
	2.1637	0.5599	0.776
3.2	0.1930	0.0282	0.467
	0.4016	0.0953	0.760
	0.6146	0.1607	0.837
	0.8318	0.2227	0.857
	1.0530	0.2825	0.859
	1.2782	0.3395	0.850
	1.5070	0.3941	0.837
	1.7397	0.4469	0.822
	1.9751	0.4970	0.805
	2.2132	0.5441	0.787
	2.4535	0.5891	0.769
3.4	0.3075	0.0572	0.633
	0.5400	0.1259	0.793
	0.7770	0.1926	0.843
	1.0184	0.2555	0.853
	1.2639	0.3161	0.850
	1.5134	0.3740	0.840
	1.7663	0.4297	0.827
	2.0223	0.4829	0.812
	2.2814	0.5325	0.794
	2.5427	0.5795	0.775
	2.8063	0.6262	0.759
3.6	0.2210	0.0242	0.395
	0.4746	0.0963	0.731
	0.7330	0.1665	0.817
	0.9961	0.2334	0.843
	1.5352	0.3577	0.840
	1.8104	0.4162	0.829
	2.0888	0.4724	0.814
	2.3701	0.5250	0.797
	2.6544	0.5740	0.778
	2.9406	0.6221	0.762
3.8	0.4215	0.0719	0.649
	0.7030	0.1454	0.786
	0.9895	0.2160	0.829
	1.2805	0.2824	0.838
	1.5758	0.3471	0.835
	1.8748	0.4073	0.827
	2.1778	0.4655	0.815
	2.4833	0.5216	0.748
	2.7915	0.5724	0.779
	3.1017	0.6211	0.761

TABLE V

8 BLADED PROP-FAN PERFORMANCE

0.70 MACH NUMBER

J	C_P	$C_{T_{Net}}$	η_{Net}
2.6	0.4030	0.1295	0.836
	0.5661	0.1881	0.864
	0.7334	0.2447	0.867
	0.9046	0.2985	0.858
	1.0795	0.3502	0.844
	1.2577	0.4002	0.828
	1.4390	0.4483	0.810
	1.6228	0.4939	0.791
	1.8092	0.5373	0.772
	1.9984	0.5804	0.755
2.8	0.2639	0.0672	0.713
	0.4398	0.1302	0.830
	0.6202	0.1907	0.861
	0.8047	0.2489	0.866
	0.9933	0.3044	0.858
	1.1855	0.3575	0.845
	1.3809	0.4087	0.829
	1.5793	0.4580	0.812
	1.7810	0.5048	0.794
	1.9852	0.5491	0.775
3.0	0.1254	0.0107	0.256
	0.3163	0.0769	0.729
	0.5119	0.1418	0.831
	0.7122	0.2039	0.859
	0.9162	0.2635	0.863
	1.1243	0.3202	0.854
	1.3361	0.3747	0.841
	1.5514	0.4271	0.826
	1.7698	0.4773	0.809
	1.9914	0.5247	0.790
3.2	0.1959	0.0290	0.474
	0.4086	0.0974	0.763
	0.6261	0.1639	0.838
	0.8480	0.2270	0.856
	1.0741	0.2877	0.857
	1.3042	0.3456	0.848
	1.5381	0.4010	0.835
	1.7753	0.4545	0.819
	2.0156	0.5047	0.801
	2.2598	0.5527	0.783
3.4	0.3122	0.0584	0.636
	0.5490	0.1284	0.795
	0.7905	0.1960	0.843
	1.0366	0.2598	0.852
	1.2869	0.3213	0.849
	1.5413	0.3800	0.838
	1.7992	0.4364	0.825
	2.0604	0.4902	0.809
	2.3242	0.5400	0.790
3.6	0.2240	0.0248	0.399
	0.4818	0.0980	0.733
	0.7447	0.1692	0.818
	1.0124	0.2370	0.843
	1.2846	0.3014	0.845
	1.5610	0.3631	0.838
	1.8412	0.4224	0.826
	2.1246	0.4790	0.812
	2.4111	0.5319	0.794
	2.7002	0.5812	0.775
3.8	0.4275	0.0732	0.651
	0.7135	0.1476	0.786
	1.0046	0.2192	0.829
	1.3004	0.2863	0.837
	1.6006	0.3519	0.833
	1.9045	0.4129	0.825
	2.2120	0.4715	0.813
	2.5232	0.5281	0.795
	2.8363	0.5790	0.776
4.0	0.3890	0.0538	0.554
	0.6999	0.1315	0.751
	1.0161	0.2060	0.811
	1.3372	0.2765	0.827
	1.6626	0.3446	0.826
	1.9921	0.4078	0.820
	2.3251	0.4703	0.808
	2.6623	0.5277	0.793
	3.0010	0.5807	0.774

TABLE V (Cont)

J	C_p	$C_{T_{Net}}$	η_{Net}
4.2	0.3695	0.0399	0.454
	0.7070	0.1207	0.717
	1.0500	0.1980	0.792
	1.3979	0.2715	0.816
	1.7504	0.3406	0.817
	2.1070	0.4086	0.813
	2.4673	0.4718	0.803
	2.8317	0.5312	0.788
	3.1981	0.5865	0.770

TABLE VI

8 BLADED PROP-FAN PERFORMANCE

0.75 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.8	0.2708	0.0698	0.722
	0.4535	0.1350	0.834
	0.6410	0.1972	0.861
	0.8331	0.2572	0.864
	1.0292	0.3141	0.855
	1.2295	0.3687	0.840
	1.4331	0.4215	0.824
	1.6400	0.4716	0.805
	1.8500	0.5193	0.786
	2.0626	0.5647	0.767
3.0	0.3239	0.0794	0.735
	0.5259	0.1462	0.833
	0.7327	0.2098	0.859
	0.9440	0.2710	0.861
	1.1593	0.3290	0.851
	1.3736	0.3847	0.837
	1.6015	0.4385	0.821
	1.8275	0.4892	0.803
	2.0567	0.5373	0.783
3.2	0.4177	0.1000	0.766
	0.6414	0.1682	0.839
	0.8699	0.2327	0.859
	1.1026	0.2946	0.855
	1.3397	0.3537	0.845
	1.5806	0.4103	0.831
	1.8250	0.4649	0.815
	2.0725	0.5157	0.796
3.4	0.5630	0.1314	0.794
	0.8077	0.2005	0.844
	1.0599	0.2654	0.851
	1.3167	0.3280	0.847
	1.5804	0.3881	0.835
	1.8454	0.4455	0.821
	2.1135	0.4999	0.804
	2.3849	0.5505	0.785
	2.6582	0.5985	0.766
3.6	0.2279	0.0257	0.406
	0.4916	0.1004	0.736
	0.7609	0.1731	0.819
	1.0348	0.2419	0.842
	1.3136	0.3086	0.843
	1.5968	0.3702	0.835
	1.8839	0.4307	0.823
	2.1741	0.4878	0.808
	2.4679	0.5412	0.789
	2.7634	0.5907	0.770
3.8	0.4356	0.0749	0.654
	0.7279	0.1508	0.787
	1.0251	0.2235	0.829
	1.3274	0.2916	0.835
	1.6344	0.3583	0.831
	1.9451	0.4202	0.822
	2.2594	0.4792	0.809
	2.5771	0.5364	0.791
	2.8973	0.5878	0.771
4.0	0.3960	0.0551	0.557
	0.7130	0.1341	0.752
	1.0356	0.2098	0.810
	1.3632	0.2812	0.825
	1.6954	0.3504	0.824
	2.0317	0.4146	0.818
	2.3714	0.4776	0.805
	2.7153	0.5356	0.789
	3.0607	0.5886	0.769
4.2	0.3760	0.0409	0.457
	0.7195	0.1228	0.717
	1.0692	0.2014	0.791
	1.4237	0.2759	0.814
	1.7831	0.3461	0.815
	2.1466	0.4148	0.810
	2.5136	0.4788	0.799
	2.8849	0.5385	0.784
4.4	0.3794	0.0325	0.377
	0.7517	0.1174	0.687
	1.1298	0.1984	0.773
	1.5132	0.2753	0.800
	1.9015	0.3476	0.804
	2.2940	0.4189	0.801
	2.8699	0.4840	0.792
	3.0895	0.5457	0.777

TABLE VII

8 BLADED PROP-FAN PERFORMANCE

0.80 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.8	0.2800	0.0727	0.727
	0.4716	0.1405	0.834
	0.6687	0.2050	0.858
	0.8708	0.2673	0.859
	1.0776	0.3261	0.847
	1.2887	0.3827	0.832
	1.5037	0.4374	0.814
	1.7221	0.4888	0.795
	1.9438	0.5376	0.774
	2.1584	0.5855	0.756
3.0	0.3343	0.0826	0.741
	0.5451	0.1517	0.835
	0.7612	0.2174	0.857
	0.9821	0.2807	0.857
	1.2076	0.3406	0.846
	1.4373	0.3980	0.831
	1.6709	0.4535	0.814
	1.9079	0.5053	0.795
	2.1481	0.5545	0.774
3.2	0.4310	0.1037	0.770
	0.6636	0.1741	0.840
	0.9012	0.2406	0.854
	1.1439	0.3046	0.852
	1.3908	0.3651	0.840
	1.6420	0.4234	0.825
	1.8970	0.4793	0.809
	2.1550	0.5308	0.788
3.4	0.5776	0.1359	0.800
	0.8343	0.2067	0.842
	1.0963	0.2737	0.849
	1.3626	0.3389	0.846
	1.6336	0.3990	0.830
	1.9085	0.4577	0.815
	2.1866	0.5128	0.797
3.6	0.5043	0.1034	0.738
	0.7820	0.1779	0.819
	1.0652	0.2486	0.840
	1.3531	0.3167	0.843
	1.6457	0.3798	0.831
	1.9424	0.4415	0.818
	2.2428	0.4999	0.802

J	C_p	$C_{T_{Net}}$	η_{Net}
3.8	0.4458	0.0771	0.657
	0.7464	0.1548	0.788
	1.0527	0.2292	0.827
	1.3643	0.2990	0.833
	1.6803	0.3656	0.827
	2.0005	0.4301	0.817
	2.3243	0.4908	0.802
4.0	0.7302	0.1374	0.753
	1.0616	0.2149	0.810
	1.3983	0.2874	0.822
	1.7397	0.3581	0.823
	2.0853	0.4235	0.812
4.2	0.7363	0.1259	0.718
	1.0946	0.2059	0.790
	1.4582	0.2815	0.811
	1.8268	0.3531	0.812
	2.1998	0.4217	0.805
4.4	0.7678	0.1200	0.745
	1.1548	0.2025	0.771
	1.5474	0.2807	0.798
	1.9449	0.3542	0.801
	2.3468	0.4265	0.799
4.6	0.8282	0.1197	0.665
	1.2459	0.2043	0.754
	1.6691	0.2845	0.784
	2.0973	0.3601	0.790
	2.5298	0.4328	0.789
4.8	0.9215	0.1248	0.650
	1.3714	0.2114	0.740
	1.8270	0.2933	0.771
	2.2875	0.3706	0.778
	2.7523	0.4447	0.776

TABLE VIII

SLIPSTREAM CHARACTERISTICS

J	C_p	ϕ	$\Delta V/V$
0.4	0.2	24.40	0.1132
	0.4	30.95	0.1223
	0.6	33.50	0.1245
	0.8	35.50	0.1240
	1.0	37.15	0.1228
	1.2	38.40	0.1210
0.6	0.2	16.10	0.0852
	0.4	21.30	0.1030
	0.6	24.90	0.1131
	0.8	27.20	0.1181
	1.0	29.10	0.1212
	1.2	30.70	0.1233
	1.4	32.00	0.1245
	1.6	33.10	0.1251
0.8	0.2	10.00	0.0595
	0.4	15.30	0.0813
	0.6	18.55	0.0950
	0.8	20.80	0.1030
	1.0	22.75	0.1085
	1.2	24.50	0.1129
	1.4	26.00	0.1160
	1.6	27.45	0.1185
1.0	0.2	6.40	0.0360
	0.4	10.70	0.0605
	0.6	13.75	0.0772
	0.8	16.10	0.0867
	1.0	18.10	0.0933
	1.2	19.80	0.0988
	1.4	21.20	0.1032
	1.6	22.40	0.1070
	1.8	24.35	0.1099
1.2	0.2	4.70	0.0240
	0.4	7.93	0.0435
	0.6	10.55	0.0594
	0.8	12.55	0.0701
	1.0	14.30	0.0781
	1.2	15.90	0.0850
	1.4	17.40	0.0904
	1.6	18.60	0.0952
	1.8	19.74	0.0995
1.4	0.2	3.50	0.0180
	0.4	6.10	0.0336
	0.6	8.23	0.0474
	0.8	10.10	0.0585
	1.0	11.70	0.0670
	1.2	13.18	0.0732
	1.4	14.50	0.0786
	1.6	15.70	0.0834
	1.8	16.70	0.8800
1.6	0.2	2.53	0.0143
	0.4	4.73	0.0268
	0.6	6.53	0.0384
	0.8	8.20	0.0485
	1.0	9.62	0.0569
	1.2	10.98	0.0637
	1.4	12.22	0.0689
	1.6	13.40	0.0736
	1.8	14.45	0.0779
	2.0	15.40	0.0820
1.8	0.2	2.03	0.0116
	0.4	3.83	0.0228
	0.6	5.36	0.0330
	0.8	6.77	0.0419
	1.0	8.10	0.0490
	1.2	9.33	0.0550
	1.4	10.50	0.0603
	1.6	11.60	0.0650
	1.8	12.57	0.0695
	2.0	13.52	0.0733
2.0	0.2	1.70	0.0102
	0.4	3.15	0.0193
	0.6	4.50	0.0280
	0.8	5.78	0.0360
	1.0	6.97	0.0431
	1.2	8.05	0.0494
	1.4	9.13	0.0547
	1.6	10.10	0.0593
	1.8	11.02	0.0638
	2.0	11.90	0.0678
	2.2	12.65	0.0715

TABLE VIII (Cont)

J	C_p	ϕ	$\Delta V/V$	J	C_p	ϕ	$\Delta V/V$
2.2	0.2	1.40	0.0092	3.0	0.2	0.75	0.0059
	0.4	2.70	0.0170		0.4	1.50	0.0105
	0.6	3.90	0.0243		0.6	2.25	0.0152
	0.8	4.98	0.0310		0.8	3.00	0.0199
	1.0	6.02	0.0375		1.0	3.75	0.0241
	1.2	7.03	0.0432		1.2	4.50	0.0282
	1.4	8.00	0.0482		1.4	5.25	0.0325
	1.6	8.92	0.0530		1.6	6.00	0.0369
	1.8	9.82	0.0573		1.8	6.75	0.0410
	2.0	10.69	0.0615		2.0	7.50	0.0449
	2.2	11.48	0.0655		2.2	8.25	0.0488
2.4	0.2	1.22	0.0082	3.2	0.2	0.70	0.0052
	0.4	2.30	0.0145		0.4	1.40	0.0095
	0.6	3.32	0.0205		0.6	2.09	0.0140
	0.8	4.30	0.0263		0.8	2.78	0.0185
	1.0	5.28	0.0319		1.0	3.48	0.0227
	1.2	6.23	0.0372		1.2	4.18	0.0265
	1.4	7.13	0.0425		1.4	4.87	0.0302
	1.6	8.00	0.0473		1.6	5.57	0.0342
	1.8	8.83	0.0520		1.8	6.26	0.0379
	2.0	9.60	0.0563		2.0	6.96	0.0418
	2.2	10.32	0.0602		2.2	7.66	0.0455
2.6	0.2	1.03	0.0072	3.4	0.2	0.65	0.0045
	0.4	2.00	0.0122		0.4	1.30	0.0088
	0.6	2.90	0.0182		0.6	1.96	0.0129
	0.8	3.78	0.0237		0.8	2.61	0.0169
	1.0	4.63	0.0320		1.0	3.26	0.0209
	1.2	5.50	0.0338		1.2	3.91	0.0245
	1.4	6.35	0.0385		1.4	4.56	0.0282
	1.6	7.20	0.0433		1.6	5.22	0.0319
	1.8	8.03	0.0478		1.8	5.87	0.0352
	2.0	8.80	0.0523		2.0	6.52	0.0388
	2.2	9.50	0.0568		2.2	7.17	0.0420
2.8	0.2	0.83	0.0015	3.6	0.2	0.60	0.0040
	0.4	1.66	0.0115		0.4	1.20	0.0078
	0.6	3.00	0.0168		0.6	1.80	0.0118
	0.8	3.33	0.0219		0.8	2.40	0.0158
	1.0	4.16	0.0257		1.0	3.00	0.0192
	1.2	4.99	0.0312		1.2	3.60	0.0225
	1.4	5.82	0.0359		1.4	4.20	0.0258
	1.6	6.66	0.0402		1.6	4.80	0.0292
	1.8	7.49	0.0445		1.8	5.60	0.0323
	2.0	8.32	0.0488		2.0	6.00	0.0355
	2.2	9.15	0.0531		2.2	6.60	0.0387

TABLE VIII (Cont)

J	C_p	ϕ	$\Delta V/V$
3.8	0.2	0.56	0.0033
	0.4	1.12	0.0068
	0.6	1.68	0.0103
	0.8	2.24	0.0137
	1.0	2.80	0.0170
	1.2	3.36	0.0200
	1.4	3.92	0.0232
	1.6	4.48	0.0263
	1.8	5.04	0.0292
	2.0	5.60	0.0320
	2.2	6.16	0.0345
4.2	0.2	0.46	0.0028
	0.4	0.93	0.0062
	0.6	1.39	0.0095
	0.8	1.86	0.0125
	1.0	2.32	0.0155
	1.2	2.78	0.0182
	1.4	3.25	0.0210
	1.6	3.71	0.0238
	1.8	4.18	0.0263
	2.0	4.64	0.0285
	2.2	5.10	0.0308
4.6	0.2	0.40	0.0024
	0.4	0.79	0.0052
	0.6	1.19	0.0080
	0.8	1.58	0.0108
	1.0	1.98	0.0132
	1.2	2.38	0.0155
	1.4	2.77	0.0182
	1.6	3.17	0.0203
	1.8	3.56	0.0223
	2.0	3.96	0.0243
	2.2	4.36	0.0262

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

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PROP-FAN PERFORMANCE ESTIMATION

FOR THE

TEN (10) BLADE PROP-FAN CONFIGURATION

October 31, 1977

PROP-FAN PERFORMANCE ESTIMATION

This data package provides Prop-Fan Performance in a non-dimensional coefficient format which permits the user to estimate performance over a broad range of operating conditions. The data is presented in tabular form for ease of computer application.

The performance is presented in terms of net thrust coefficient ($C_{T_{Net}}$) as a function of power coefficient (C_p) for constant values of advance ratio (J). The following tables are included:

I	Mach Number	<.55
II	Mach Number	=0.55
III	Mach Number	=0.60
IV	Mach Number	=0.65
V	Mach Number	=0.70
VI	Mach Number	=0.75
VII	Mach Number	=0.80
VIII	Slipstream Characteristics	

The 0.55 to 0.80 Mach number tables also include a tabulation of net efficiency (η_{Net}) to allow for a visual estimation of performance level.

The non-dimensional coefficients are defined in engineering terms as English Units:

$$J = \frac{101.4\ M_o\ C_K}{ND} = \frac{101.4\ V}{ND}$$

$$C_p = \frac{SHP\ (\rho o/\rho)}{20\ (ND/10{,}000)^3\ D^2} = \frac{SHP\ (\rho o/\rho)}{2000\ (N/1000)^3\ (D/10)^5}$$

$$T_{NET} = 66.1\ (ND/10{,}000)^2\ D^2\ C_{T_{NET}}/(\rho o/\rho)$$

$$T_{NET} = 6610\ (N/1000)^2\ (D/10)^4\ C_{T_{NET}}/(\rho o/\rho)$$

where: T_{NET} = Uninstalled Prop-Fan net thrust, pounds

N = Prop-Fan rotational speed, rpm

D = Prop-Fan tip diameter, feet

ρ_o/ρ = Density ratio, sea level ISA to ambient conditions (ρo=0.002378 lb-sec^2/ft^4)

M_o = Free stream Mach number

C_K = Speed of sound, knots

V = Free stream velocity, true airspeed, knots

where: ND = (TS) (60)/π

TS = Tip speed, ft per second

ϕ = Average swirl angle, degrees

ΔV = Incremental induced axial velocity immediately behind disk, knots

In SI Units:

$$J = \frac{60\ M_o\ C_{m/s}}{ND} = \frac{60\ V}{ND}$$

$$C_p = \frac{KW\ (\rho_o/\rho)}{5.674\left(\frac{ND}{1000}\right)^3 D^2}$$

$$T_{NET} = 3409.2\left(\frac{ND}{1000}\right)^2 D^2\ C_{T_{NET}}/\ (\rho_o/\rho)$$

where K_W = power, kilowatts

T_{NET} = Uninstalled Prop-Fan net thrust, newtons

N = Prop Fan Rotational Speed, RPM

D = Prop-Fan Diameter, Meters

ρ_o/ρ = Density ratio, sea level ISA to ambient conditions

M_o = Free stream Mach number

$C_{m/s}$ = Speed of sound, meters per second

V = Free stream velocity, meters per second

ϕ = Average swirl angle degrees

ΔV = Incremental axial induced velocity immediately behind disk, meters per second

where ND = (TS) (60) / π

TS = tip speed, meters per second

The "Net Thrust (T_{NET})" is the uninstalled thrust of the Prop-Fan rotor operating in the presence of a nacelle. The buoyancy force between the rotor and nacelle face has been removed from the rotor thrust, and therefore it should not be included in the nacelle drag. Installed propulsive thrust is obtained by adding the uninstalled net thrust (T_{NET}) to the core engine jet thrust and then subtracting the drag of the nacelle and the losses due to nacelle/wing interference.

The slipstream characteristics are also presented in tabular form. Average swirl angle (ϕ) and incremental axial induced velocity immediately behind the disk over freestream velocity ($\Delta V/V$) are presented as a function of power coefficient (C_p) for given values of advance ratio (J). Theoretically the induced axial velocity doubles in the ultimate wake which is approximately two diameters downstream.

SAMPLE PROBLEMS

English Units

Given: 5409 lb installed thrust required at 0.80 Mach number at 35,000 ft., ISA

Select the diameter required for an:

SHP/D^2 of 37.5 for a 10 bladed Prop-Fan operating at 800 feet per second tip speed

Calculate: $ND = (800)\ (60)\ /\ \pi = 15{,}279$

$$C_p = \frac{(SHP/D^2)\ (\rho o/\rho)}{20\ (ND/10000)^3}$$

$$= \frac{(37.5)\ (3.2196)}{(20)\ (1.5279)^3}$$

$$= 1.692$$

$$J = (101.4)\ (Mo)\ (C_K)\ /\ ND$$

$$= (101.4)\ (0.80)\ (576.3)\ /\ (15{,}279)$$

$$= 3.060$$

$$C_{T_{Net}} = 0.458 \text{ (Table VII)}$$

$$\eta_{Net} = \frac{C_{T_{Net}}}{C_p}\ J = \frac{(0.458)\ (3.060)}{1.692} = 0.828$$

and $T_{Net} = 66.1\ (D)^2\ (ND/10000)^2\ C_{T_{Net}}\ /\ (\rho o/\rho)$

$$= 66.1\ (D)^2\ (1.5279)^2\ (0.458)\ /\ (3.2196)$$

$$= 21.951\ D^2$$

For the engine selected, calculate a diameter such that:

Net Thrust + Jet Thrust - Nacelle Drag - Wing Int. Drag = 5409 lbs

This is an iterative process.

For example:

Diameter	= 15.56 feet
T_{net}	= 5315 pounds
T_{jet}	= +408 pounds
$D_{nacelle}$	= -209 pounds
D_{interf}	= -105 pounds
$T_{installed}$	= 5409 pounds

$SHP = (SHP/D^2)\ D^2 = (37.5)\ (15.56)^2 = 9079$

For takeoff, climb, loiter and other performance points at Mach numbers less than 0.55, utilize table I.

For example, for the 10 bladed / 15.56 foot diameter Prop-Fan calculate the power required for a net thrust of 20,630 pounds at 0.25 Mach number at Sea Level, ISA at 800 feet per second tip speed.

Calculate: -

$$J = (101.4)\ (Mo)\ (C_K)\ /\ ND$$

$$= (101.4)\ (0.25)\ (661.2)\ /\ 15279$$

$$= 1.097$$

$$C_{T_{Net}} = (T_{Net})\ (\rho o/\rho)\ /\ 66.1\ (ND/10{,}000)^2\ D^2$$

$$= (20{,}630)\ (1.0)\ /\ 66.1\ (1.5279)^2\ (15.56)^2$$

$$= 0.552$$

From Table I $C_p = 0.984$

$$SHP = (20)\ (ND/10{,}000)^3\ D^2\ C_p\ /\ (\rho o/\rho)$$

$$= (20)\ (1.5279)^3\ (15.56)^2\ (0.984)\ /\ 1.0$$

$$= 17{,}000$$

SI Units

Given: 24,040 Newtons of installed thrust at 0.80 Mach number at 10,668 meters ISA altitude

Select the diameter required for a:

$KW/D^2 = 301\ KW/m^2$ for a 10 bladed Prop-Fan operating at 243.84 mps tip speed

Calculate: $ND = (243.84)\ (60)\ /\ \pi = 4657$

$$C_p = \frac{(KW/D^2)\ (\rho o/\rho)}{5.674 \left(\frac{ND}{1000}\right)^3}$$

$$= \frac{(301)\ (3.2196)}{5.674\ (4.657)^3}$$

$$= 1.692$$

$$J = \frac{(60)\ (Mo)\ (C_{m/s})}{ND}$$

$$= \frac{(60)\ (0.8)\ (296.48)}{4657} = 3.06$$

$$C_{T_{Net}} = 0.458 \text{ (Table VII)}$$

$$\eta_{Net} = \frac{C_{T_{Net}}}{C_p}\ J = \frac{(0.458)\ (3.06)}{1.692} = 0.828$$

and $$T_{NET} = 340.42\ \frac{ND}{1000}^{\ 2}\ D^2\ C_{T_{Net}}\ /\ (\rho o/\rho)$$

$$= 340.42\ (4.657)^2\ (D^2)\ (0.458)\ /\ 3.2196$$

$$T_{Net} = (1050.2)\ (D^2)$$

For the engine selected, calculate a diameter such that:

Net Thrust + Jet Thrust - Nacelle Drag - Wing Int. Drag = 24040 Newtons

This is an iterative process.

For example:

Diameter	= 4.743 meters
T_{net}	= 23622 newtons
T_{jet}	= +1815 newtons
$D_{nacelle}$	= -930 newtons
D_{interf}	= -467 newtons
$T_{installed}$	= 24040 newtons

$KW = (KW/D^2)\ (D^2) = (301)\ (4.743)^2 = 6771$

For takeoff, climb, loiter and other performance points for Mach Numbers less than 0.55, utilize table I which covers the low advance ratio range of operation.

For example, for the 10 blade, 4.743 meter diameter Prop-Fan, calculate the power required for a net thrust of 91762 newtons at 0.25 Mach number at Sea Level, ISA at a 243.84 meters per second tip speed.

Calculate: -

$$J = (60)\ (Mo)\ (Cm/s)\ /\ ND$$

$$= (60)\ (0.25)\ (340.2)\ /\ 4657$$

$$= 1.096$$

$$C_{T_{Net}} = (T_{net})\ (\rho o/\rho)\ /\ 340.42\ (ND/1000)^2\ D^2$$

$$= (91762)\ (1)\ /340.42\ (4.657)^2\ (4.743)^2$$

$$= 0.552$$

From Table I $C_p = 0.984$

$$KW = 5.674\ (ND/1000)^3\ D^2\ C_p\ /\ (\rho o/\rho)$$

$$= 5.674\ (4.657)^3\ (4.743)^2\ (0.984)\ /\ 1.0)$$

$$= 12686$$

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TABLE I

10 BLADED PROP-FAN PERFORMANCE

< 0.55 MACH NUMBER

J	C_P	$C_{T_{Net}}$	J	C_P	$C_{T_{Net}}$	J	C_P	$C_{T_{Net}}$
0	0.1073	0.2062	0.6	0.0629	0.0657	1.2	0.1036	0.0663
	0.1519	0.2675		0.1213	0.1397		0.2445	0.1685
	0.2072	0.3288		0.1967	0.2148		0.4031	0.2678
	0.2725	0.3872		0.2874	0.2986		0.5746	0.3625
	0.3442	0.4401		0.3917	0.3780		0.7622	0.4506
	0.4238	0.4860		0.5108	0.4548		0.9728	0.5296
	0.5118	0.5237		0.6491	0.5266		1.2006	0.5957
	0.6085	0.5528		0.8075	0.5912		1.4424	0.6523
	0.7091	0.5709		0.9778	0.6426		1.6937	0.6933
	0.7996	0.5812		1.1584	0.6789		1.7972	0.7052
	0.8969	0.5846		1.3470	0.7152		1.9012	0.7129
	0.9702	0.5733		1.5456	0.7537		2.0043	0.7185
	1.0395	0.5565		1.7334	0.7664			
	1.0843	0.5300				1.4	0.0465	0.0150
	1.1306	0.4983	0.8	0.0932	0.0864		0.2120	0.1263
				0.1807	0.1714		0.3952	0.2341
0.2	0.1000	0.1650		0.2847	0.2576		0.5928	0.3358
	0.2000	0.2940		0.4039	0.3426		0.8040	0.4300
	0.3000	0.3890		0.5367	0.4246		1.0387	0.5148
	0.4000	0.4665		0.6885	0.5012		1.2947	0.5859
	0.5000	0.5205		0.8619	0.5701		1.5635	0.6451
	0.6000	0.5685		1.0483	0.6285		1.8381	0.6866
	0.7000	0.5980		1.2445	0.6726		2.1251	0.7122
	0.8000	0.6255		1.4527	0.7022			
	0.9000	0.6500		1.6619	0.7296	1.6	0.1767	0.0896
	1.0000	0.6695		1.7503	0.7435		0.3888	0.2063
	1.1000	0.6800		1.9100	0.7494		0.6166	0.3150
							0.8570	0.4150
0.4	0.0819	0.1147	1.0	0.0468	0.0264		1.1211	0.5064
	0.1322	0.1831		0.1493	0.1196		1.4086	0.5816
	0.1976	0.2572		0.2699	0.2132		1.7063	0.6415
	0.2775	0.3332		0.4071	0.3048		2.0114	0.6838
	0.3700	0.4085		0.5572	0.3929		2.3277	0.7085
	0.4778	0.4813		0.7251	0.4750			
	0.6045	0.5490		0.9157	0.5488	1.8	0.1451	0.0610
	0.7499	0.6050		1.1207	0.6107		0.3912	0.1861
	0.9062	0.6501		1.3377	0.6625		0.6537	0.3024
	1.0752	0.6979		1.5661	0.6985		0.9289	0.4098
	1.2452	0.7328		1.8015	0.7219		1.2265	0.5053
	1.4304	0.7700		1.8902	0.7283		1.5478	0.5828
	1.5945	0.7712		1.9849	0.7344		1.8784	0.6423
				2.0763	0.7367		2.2177	0.6839
							2.5674	0.7053

TABLE I (Cont)

10 BLADED PROP-FAN PERFORMANCE

< 0.55 MACH NUMBER

J	C_p	$C_{T_{Net}}$
2.0	0.1249	0.0426
	0.2331	0.0968
	0.3579	0.1498
	0.4692	0.2019
	0.5902	0.2517
	0.7124	0.2997
	0.8361	0.3462
	0.9621	0.3911
	1.0913	0.4338
	1.2239	0.4740
	1.3608	0.5114
	1.5037	0.5459
	1.6486	0.5765
	1.7924	0.6024
	1.9398	0.6265
2.2	0.0616	0.0069
	0.1896	0.0652
	0.3208	0.1221
	0.4547	0.1778
	0.5917	0.2318
	0.7308	0.2827
	0.8705	0.3319
	1.0119	0.3793
	1.1558	0.4246
	1.3034	0.4669
	1.4549	0.5066
	1.6121	0.5426
	1.7751	0.5755
	1.9350	0.6021
2.4	0.1553	0.0433
	0.3047	0.1038
	0.4582	0.1629
	0.6109	0.2205
	0.7682	0.2741
	0.9259	0.3259
	1.0846	0.3756
	1.2456	0.4231
	1.4103	0.4675
	1.5791	0.5089
	1.7553	0.5463
	1.9344	0.5800

J	C_p	$C_{T_{Net}}$
2.6	0.1414	0.0319
	0.3106	0.0959
	0.4823	0.1581
	0.6559	0.2184
	0.8327	0.2748
	1.0099	0.3288
	1.1879	0.3806
	1.3683	0.4299
	1.5520	0.4759
	1.7401	0.5183
	1.9341	0.5564
	2.1356	0.5905
2.8	0.1356	0.0319
	0.3463	0.0990
	0.5394	0.1640
	0.7342	0.2266
	0.9323	0.2850
	1.1307	0.3411
	1.3298	0.3946
	1.5310	0.4452
	1.7363	0.4920
	1.9462	0.5349
	2.1626	0.5728
	2.3866	0.6061
3.0	0.2062	0.0439
	0.4199	0.1135
	0.6363	0.1808
	0.8541	0.2453
	1.0752	0.3051
	1.2961	0.3626
	1.5182	0.4173
	1.7427	0.4685
	1.9716	0.5155
	2.2061	0.5579
3.2	0.3016	0.0677
	0.5403	0.1393
	0.7812	0.2082
	1.0244	0.2736
	1.2697	0.3347
	1.5151	0.3931
	1.7618	0.4482
	2.0120	0.4992
	2.2674	0.5452

TABLE II

10 BLADED PROP-FAN PERFORMANCE

0.55 MACH NUMBER

J	C_P	$C_{T_{Net}}$	η_{Net}
2.0	0.5315	0.2317	0.872
	0.6497	0.2794	0.860
	0.7716	0.3258	0.854
	0.8969	0.3713	0.828
	1.0250	0.4156	0.811
	1.1566	0.4587	0.792
	1.2902	0.5000	0.775
	1.4260	0.5406	0.759
	1.5640	0.5792	0.740
	1.7039	0.6154	0.722
	1.7638	0.5820	0.660
2.2	0.3923	0.1539	0.864
	0.5199	0.2071	0.876
	0.6512	0.2580	0.872
	0.7860	0.3067	0.859
	0.9240	0.3541	0.844
	1.0650	0.4005	0.827
	1.2090	0.4454	0.810
	1.3555	0.4886	0.793
	1.5045	0.5301	0.775
	1.6558	0.7516	0.759
	1.8090	0.6089	0.740
2.4	0.3539	0.1360	0.851
	0.5265	0.1917	0.874
	0.6728	0.2456	0.876
	0.8227	0.2970	0.867
	0.9759	0.3466	0.853
	1.1322	0.3949	0.837
	1.2916	0.4419	0.821
	1.4537	0.4869	0.804
	1.6182	0.5301	0.786
	1.7851	0.5729	0.771
2.6	0.2408	0.0674	0.728
	0.3964	0.1278	0.839
	0.5561	0.1863	0.871
	0.7197	0.2428	0.877
	0.8869	0.2967	0.870
	1.0575	0.3484	0.857
	1.2313	0.3987	0.842
	1.4081	0.4475	0.826
	1.5877	0.4942	0.809
	1.7701	0.5389	0.792
2.8	0.2617	0.0669	0.715
	0.4364	0.1300	0.835
	0.6152	0.1909	0.868
	0.7980	0.2496	0.876
	0.9846	0.3057	0.869
	1.1745	0.3594	0.857
	1.3678	0.4115	0.843
	1.5642	0.4620	0.827
	1.7638	0.5101	0.810
	1.9670	0.5564	0.792
3.0	0.3151	0.0772	0.735
	0.5109	0.1427	0.839
	0.7109	0.2055	0.867
	0.9149	0.2661	0.873
	1.1226	0.3240	0.866
	1.3340	0.3795	0.854
	1.5489	0.4333	0.840
	1.7672	0.4851	0.823
	1.9896	0.5345	0.806
	2.2139	0.5816	0.788
3.2	0.1943	0.0291	0.479
	0.4086	0.0983	0.770
	0.6281	0.1661	0.846
	0.8513	0.2303	0.866
	1.0787	0.2926	0.868
	1.3100	0.3518	0.859
	1.5451	0.4090	0.847
	1.7837	0.4642	0.833
	2.0255	0.5165	0.816
	2.2704	0.5663	0.798
	2.5177	0.6148	0.782
3.4	0.3116	0.0592	0.645
	0.5510	0.1304	0.805
	0.7951	0.1994	0.853
	1.0435	0.2648	0.863
	1.2963	0.3290	0.860
	1.5530	0.3883	0.851
	1.8134	0.4470	0.838
	2.0774	0.5031	0.823
	2.3442	0.5551	0.805
	2.6136	0.6050	0.787

TABLE III

10 BLADED PROP-FAN PERFORMANCE

0.60 MACH NUMBER

J	C_p	$C_{T_{Net}}$	η_{Net}
2.2	0.5330	0.2122	0.876
	0.6682	0.2642	0.870
	0.8072	0.3140	0.856
	0.9494	0.3524	0.840
	1.0949	0.4097	0.823
	1.2434	0.4555	0.806
	1.3946	0.4994	0.788
	1.5482	0.5416	0.770
	1.7041	0.5834	0.753
	1.8621	0.6215	0.734
2.4	0.3910	0.1389	0.853
	0.5366	0.1955	0.874
	0.6862	0.2504	0.876
	0.8396	0.3025	0.865
	0.9965	0.3530	0.850
	1.1565	0.4022	0.835
	1.3198	0.4498	0.818
	1.4856	0.4953	0.800
	1.6541	0.5390	0.783
	1.8249	0.5827	0.766
2.6	0.2441	0.0686	0.731
	0.4024	0.1300	0.841
	0.5649	0.1893	0.871
	0.7315	0.2467	0.877
	0.9018	0.3012	0.868
	1.0757	0.3537	0.855
	1.2529	0.4047	0.840
	1.4331	0.4540	0.823
	1.6163	0.5013	0.806
	1.8022	0.5465	0.788
2.8	0.2648	0.0680	0.719
	0.4422	0.1320	0.836
	0.6238	0.1936	0.869
	0.8096	0.2531	0.875
	0.9991	0.3098	0.868
	1.1923	0.3642	0.855
	1.3897	0.4172	0.841
	1.5897	0.4683	0.824
	1.7927	0.5168	0.807
	1.9987	0.5632	0.789

J	C_p	$C_{T_{Net}}$	η_{Net}
3.0	0.3191	0.0784	0.737
	0.5177	0.1448	0.839
	0.7207	0.2084	0.867
	0.9278	0.2697	0.872
	1.1388	0.3282	0.865
	1.2535	0.3844	0.852
	1.5718	0.4389	0.838
	1.7936	0.4909	0.821
	2.0185	0.5406	0.803
	2.2463	0.5881	0.786
3.2	0.1965	0.0277	0.483
	0.4137	0.0977	0.772
	0.6355	0.1682	0.847
	0.8618	0.2331	0.866
	1.0923	0.2960	0.868
	1.3269	0.3559	0.858
	1.5654	0.4132	0.846
	1.8075	0.4695	0.831
	2.0532	0.5222	0.814
	2.3016	0.5724	0.796
	2.5526	0.6216	0.779
3.4	0.3146	0.0600	0.648
	0.5571	0.1320	0.806
	0.8043	0.2018	0.853
	1.0560	0.2678	0.862
	1.3122	0.3326	0.860
	1.5724	0.3925	0.850
	1.8365	0.4578	0.837
	2.1050	0.5085	0.821
	2.3755	0.5609	0.803
	2.6488	0.6113	0.785
3.6	0.2232	0.0253	0.408
	0.4879	0.1009	0.744
	0.7578	0.1745	0.829
	1.0325	0.2448	0.853
	1.3118	0.3128	0.856
	1.5955	0.3762	0.850
	1.8831	0.4387	0.839
	2.1755	0.4981	0.824
	2.4698	0.5535	0.807
	2.7671	0.6060	0.788

TABLE IV

10 BLADED PROP-FAN PERFORMANCE

0.65 MACH NUMBER

J	C_P	$C_{T_{Net}}$	η Net
2.4	0.4014	0.1430	0.856
	0.5518	0.2012	0.875
	0.7064	0.2572	0.874
	0.8651	0.3106	0.862
	1.0275	0.3623	0.847
	1.1932	0.4128	0.830
	1.3621	0.4613	0.813
	1.5339	0.5078	0.794
	1.7082	0.5523	0.777
	1.8851	0.5966	0.759
2.6	0.2488	0.0705	0.737
	0.4110	0.1333	0.844
	0.5777	0.1937	0.872
	0.7487	9.2522	0.876
	0.9237	0.2522	0.876
	1.1032	0.3616	0.852
	1.2854	0.4137	0.837
	1.4706	0.4636	0.820
	1.6591	0.5117	0.802
	1.8502	0.5576	0.784
	2.0441	0.6033	0.767
2.8	0.2695	0.0696	0.723
	0.4507	0.1350	0.839
	0.6363	0.1975	0.869
	0.8262	0.2581	0.875
	1.0201	0.3157	0.867
	1.2177	0.3710	0.853
	1.4188	0.4247	0.838
	1.6233	0.4762	0.821
	1.8309	0.5254	0.804
	2.0417	0.5724	0.786
3.0	0.3238	0.0799	0.740
	0.5260	0.1474	0.841
	0.7328	0.2119	0.867
	0.9438	0.2741	0.871
	1.1589	0.3334	0.863
	1.3777	0.3904	0.850
	1.6004	0.4457	0.836
	1.8265	0.4983	0.818
	2.0564	0.5486	0.800
	2.2886	0.5967	0.783

J	C_P	$C_{T_{Net}}$	η Net
3.2	0.1988	0.0303	0.488
	0.4195	0.1014	0.774
	0.6449	0.1708	0.848
	0.8750	0.2367	0.865
	1.1094	0.3004	0.867
	1.3481	0.3610	0.857
	1.5907	0.4196	0.844
	1.8370	0.4760	0.829
	2.0875	0.5292	0.811
	2.3404	0.5799	0.793
3.4	0.3184	0.0610	0.651
	0.5644	0.1340	0.808
	0.8154	0.2046	0.853
	1.0711	0.2716	0.862
	1.3312	0.3370	0.859
	1.5956	0.3989	0.847
	1.8639	0.4576	0.835
	2.1369	0.5146	0.810
	2.4119	0.5676	0.800
3.6	0.2285	0.0258	0.412
	0.4940	0.1024	0.[illegible]46
	0.7684	0.1770	0.829
	1.0472	0.2481	0.853
	1.3308	0.3170	0.855
	1.6188	0.3811	0.849
	1.9108	0.4444	0.837
	2.2064	0.5040	0.822
	2.5053	0.5597	0.804
3.8	0.4369	0.0765	0.666
	0.7353	0.1546	0.799
	1.0389	0.2298	0.841
	1.3475	0.3005	0.848
	1.6608	0.3687	0.845
	1.9781	0.4346	0.836
	2.2992	0.4966	0.824
	2.6237	0.5565	0.806
	2.9512	0.6111	0.787
	3.2811	0.6654	0.771

TABLE V

10 BLADED PROP-FAN PERFORMANCE

0.70 MACH NUMBER

J	Cp	$C_{T_{Net}}$	η Net
2.6	0.4236	0.1379	0.847
	0.5966	0.2007	0.872
	0.7743	0.2605	0.874
	0.9560	0.3173	0.863
	1.1418	0.3724	0.848
	1.3312	0.4260	0.832
	1.5250	0.4774	0.814
	1.7209	0.5263	0.795
	1.9198	0.5738	0.777
	2.1213	0.6192	0.759
2.8	0.2758	0.0718	0.729
	0.4623	0.1388	0.842
	0.6536	0.2030	0.869
	0.8496	0.2650	0.873
	1.0497	0.3238	0.864
	1.2538	0.3805	0.850
	1.4615	0.4355	0.834
	1.6728	0.4879	0.817
	1.8871	0.5379	0.798
	2.1046	0.5863	0.781
3.0	0.3305	0.0821	0.745
	0.5378	0.1571	0.843
	0.7499	0.2168	0.867
	0.9668	0.2806	0.871
	1.1877	0.3408	0.861
	1.4126	0.3990	0.847
	1.6414	0.4553	0.832
	1.8737	0.5085	0.814
	2.1094	0.5594	0.796
	2.3485	0.7751	0.778
3.2	0.2019	0.0312	0.495
	0.4274	0.1037	0.777
	0.6581	0.1746	0.849
	0.8933	0.2416	0.865
	1.1333	0.3064	0.865
	1.3776	0.3680	0.855
	1.6260	0.4274	0.841
	1.8783	0.4850	0.826
	2.1339	0.5384	0.807
	2.3936	0.5898	0.789
3.4	0.3236	0.0623	0.655
	0.5745	0.1367	0.809
	0.8396	0.2085	0.853
	1.0915	0.2765	0.861
	1.3572	0.3429	0.857
	1.6272	0.4059	0.845
	1.9012	0.4653	0.832
	2.1788	0.5226	0.815
	2.4607	0.5763	0.296
	2.7442	0.6288	0.779
3.6	0.2288	0.0265	0.416
	0.5020	0.1043	0.748
	0.7807	0.1801	0.830
	1.0647	0.2521	0.853
	1.3535	0.3219	0.854
	1.6481	0.3871	0.847
	1.9458	0.4501	0.836
	2.2471	0.5117	0.820
	2.5517	0.5627	0.801
	2.8592	0.6213	0.783
3.8	0.4436	0.0779	0.668
	0.7470	0.1522	0.800
	1.0559	0.2335	0.840
	1.3699	0.3064	0.846
	1.6887	0.3743	0.844
	2.0117	0.44[illegible]9	0.834
	2.3385	0.5047	0.820
	2.6689	0.5638	0.803
	3.0022	0.6189	0.783
4.0	0.4010	0.0572	0.571
	0.7309	0.1400	0.766
	1.0665	0.2196	0.823
	1.4074	0.2945	0.837
	1.7531	0.3676	0.837
	2.1032	0.4358	0.830
	2.4573	0.5030	0.818
	2.8153	0.5643	0.802
	3.1758	0.6210	0.782

TABLE V (Cont)

10 BLADED PROP-FAN PERFORMANCE

0.70 MACH NUMBER

J	Cp	$C_{T_{Net}}$	η_{Net}
4.2	0.3785	0.0423	0.470
	0.7366	0.1285	0.733
	1.1007	0.2109	0.805
	1.4702	0.2893	0.826
	1.8446	0.3652	0.829
	2.2236	0.4357	0.824
	2.6067	0.50[illegible]	0.813
	2.9939	0.5686	0.798

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TABLE VI

10 BLADED PROP-FAN PERFORMANCE

0.75 MACH NUMBER

J	Cp	$C_{T_{Net}}$	η_{Net}
2.8	0.2845	0.0750	0.738
	0.4788	0.1444	0.845
	0.6785	0.2107	0.869
	0.8831	0.2748	0.871
	1.0924	0.3354	0.860
	1.3059	0.3938	0.845
	1.5233	0.4506	0.828
	1.7443	0.5042	0.809
	1.9687	0.5554	0.790
	2.1962	0.6057	0.773
3.0	0.3400	0.0851	0.751
	0.5549	0.1653	0.845
	0.7750	0.2240	0.867
	1.0000	0.2894	0.868
	1.2295	0.3514	0.857
	1.4632	0.4110	0.843
	1.7010	0.4689	0.827
	1.9424	0.5231	0.808
	2.1871	0.5749	0.789
3.2	0.4389	0.1071	0.781
	0.6768	0.1797	0.850
	0.9198	0.2485	0.864
	1.1677	0.3148	0.863
	1.4202	0.3779	0.851
	1.6770	0.4378	0.837
	1.9377	0.4970	0.820
	2.2019	0.5515	0.801
3.4	0.3307	0.0642	0.660
	0.5885	0.1404	0.811
	0.8517	0.2136	0.853
	1.1203	0.2833	0.860
	1.3936	0.3511	0.854
	1.6715	0.4143	0.843
	1.9535	0.4759	0.828
	2.2391	0.5335	0.810
	2.5292	0.5884	0.791
	2.8208	0.6418	0.774
3.6	0.2329	0.0274	0.423
	0.5428	0.1070	0.751
	0.7985	0.1844	0.831
	1.0898	0.2577	0.851
	1.3861	0.3276	0.852
	1.6872	0.3951	0.844
	1.9940	0.4593	0.832
	2.3032	0.5218	0.815
	2.6157	0.5783	0.796
	2.9312	0.6335	0.779
3.8	0.4523	0.0799	0.672
	0.7626	0.1607	0.801
	1.0787	0.2382	0.839
	1.4002	0.3124	0.845
	1.7266	0.3818	0.841
	2.0573	0.4496	0.831
	2.3920	0.5138	0.816
	2.7303	0.5233	0.798
	3.0715	0.6295	0.779
4.0	0.4085	0.0586	0.575
	0.7453	0.1429	0.767
	1.0881	0.2239	0.823
	1.4365	0.3000	0.835
	1.7898	0.3742	0.835
	2.1477	0.4437	0.827
	2.5097	0.5101	0.815
	2.8755	0.5731	0.797
	3.2440	0.6306	0.778
4.2	0.3853	0.0435	0.474
	0.7575	0.1311	0.734
	1.1219	0.2149	0.804
	1.4990	0.2944	0.825
	1.8812	0.3714	0.826
	2.2681	0.4629	0.821
	2.6591	0.5117	0.811
	3.0542	0.5769	0.793
	3.4518	0.6360	0.774

TABLE VI (Cont)

J	C_p	$C_{T_{Net}}$	η_{Net}
4.4	0.3861	0.0345	0.394
	0.7816	0.1251	0.703
	1.1834	0.2115	0.786
	1.5911	0.2490	0.813
	2.0040	0.3720	0.817
	2.4217	0.4485	0.813
	2.8433	0.5189	0.803
	3.2699	0.5851	0.787
	3.6985	0.6454	0.768

TABLE VII

10 BLADED PROP-FAN PERFORMANCE

0.80 MACH NUMBER

J	Cp	CT_{Net}	η_{Net}
2.8	0.2943	0.0782	0.744
	0.4988	0.1506	0.845
	0.7093	0.2197	0.867
	0.9254	0.2861	0.866
	1.1469	0.3491	0.852
	1.3728	0.4098	0.836
	1.6031	0.4683	0.818
	1.8377	0.5238	0.798
	2.0755	0.5765	0.779
	2.3167	0.6282	0.759
3.0	0.1324	0.0132	0.299
	0.3509	0.0886	0.757
	0.5757	0.1626	0.847
	0.8062	0.2327	0.866
	1.0421	0.3002	0.864
	1.2831	0.3643	0.852
	1.5287	0.4260	0.836
	1.7787	0.4853	0.818
	2.0325	0.5411	0.799
	2.2899	0.5954	0.780
3.2	0.2108	0.0338	0.513
	0.4526	0.1111	0.785
	0.7004	0.1862	0.851
	0.9538	0.2573	0.863
	1.2126	0.3256	0.859
	1.4764	0.3906	0.847
	1.7448	0.4533	0.832
	2.0172	0.5125	0.813
	2.2936	0.5686	0.793
	2.5743	0.6235	0.225
3.4	0.3397	0.0669	0.667
	0.6072	0.1453	0.813
	0.8806	0.2207	0.852
	1.1597	0.2925	0.858
	1.4440	0.3610	0.851
	1.7332	0.4272	0.838
	2.0267	0.4904	0.823
	2.3241	0.5490	0.803
	2.6262	0.6050	0.783
	2.9295	0.6600	0.766
3.6	0.2382	0.0285	0.430
	0.5276	0.1105	0.754
	0.8233	0.1901	0.831
	1.1248	0.2653	0.849
	1.4318	0.3372	0.849
	1.7439	0.4062	0.840
	2.0620	0.4731	0.826
	2.3826	0.5324	0.809
	2.7065	0.5931	0.789
3.8	0.4624	0.0824	0.675
	0.7844	0.1654	0.801
	1.1107	0.2448	0.838
	1.4427	0.3208	0.842
	1.7800	0.3917	0.838
	2.1217	0.4616	0.826
	2.4675	0.5265	0.811
	2.8169	0.5863	0.791
	3.1693	0.6447	0.774
4.0	0.4186	0.0605	0.578
	0.7652	0.1469	0.768
	1.1182	0.2297	0.822
	1.4771	0.3075	0.832
	1.8411	0.3821	0.832
	2.2099	0.4546	0.823
	2.5834	0.5214	0.810
	2.9599	0.5849	0.790

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TABLE VIII

SLIPSTREAM CHARACTERISTICS

J	C_p	ϕ	$\Delta V/V$
0.4	0.2	24.40	0.1132
	0.4	30.95	0.1223
	0.6	33.50	0.1245
	0.8	35.50	0.1240
	1.0	37.15	0.1228
	1.2	38.40	0.1210
0.6	0.2	16.10	0.0852
	0.4	21.30	0.1030
	0.6	24.90	0.1131
	0.8	27.20	0.1181
	1.0	29.10	0.1212
	1.2	30.70	0.1233
	1.4	32.00	0.1245
	1.6	33.10	0.1251
0.8	0.2	10.00	0.0595
	0.4	15.30	0.0813
	0.6	18.55	0.0950
	0.8	20.80	0.1030
	1.0	22.75	0.1085
	1.2	24.50	0.1129
	1.4	26.00	0.1160
	1.6	27.15	0.1185
1.0	0.2	6.40	0.0360
	0.4	10.70	0.0605
	0.6	13.75	0.0772
	0.8	16.10	0.0867
	1.0	18.10	0.0933
	1.2	19.80	0.0988
	1.4	21.20	0.1032
	1.6	22.40	0.1070
	1.8	24.35	0.1099
1.2	0.2	4.70	0.0240
	0.4	7.93	0.0435
	0.6	10.55	0.0594
	0.8	12.55	0.0701
	1.0	14.30	0.0781
	1.2	15.90	0.0850
	1.4	17.40	0.0904
	1.6	18.60	0.0952
	1.8	19.74	0.0995

J	C_p	ϕ	$\Delta V/V$
1.4	0.2	3.50	0.0180
	0.4	6.10	0.0336
	0.6	8.23	0.0474
	0.8	10.10	0.0585
	1.0	11.70	0.0670
	1.2	13.18	0.0732
	1.4	14.50	0.0786
	1.6	15.70	0.0834
	1.8	16.70	0.8800
1.6	0.2	2.53	0.0143
	0.4	4.73	0.0268
	0.6	6.53	0.0384
	0.8	8.20	0.0485
	1.0	9.62	0.0569
	1.2	10.98	0.0637
	1.4	12.22	0.0689
	1.6	13.40	0.0736
	1.8	14.45	0.0779
	2.0	15.40	0.0820
1.8	0.2	2.03	0.0116
	0.4	3.83	0.0228
	0.6	5.36	0.0330
	0.8	6.77	0.0419
	1.0	8.10	0.0490
	1.2	9.33	0.0550
	1.4	10.50	0.0603
	1.6	11.60	0.0650
	1.8	12.57	0.0695
	2.0	13.52	0.0733
2.0	0.2	1.70	0.0102
	0.4	3.15	0.0193
	0.6	4.50	0.0280
	0.8	5.78	0.0360
	1.0	6.97	0.0431
	1.2	8.05	0.0494
	1.4	9.13	0.0547
	1.6	10.10	0.0593
	1.8	11.02	0.0638
	2.0	11.90	0.0678
	2.2	12.65	0.0715

TABLE VIII (Cont)

J	C_p	ϕ	$\Delta V/V$	J	C_p	ϕ	$\Delta V/V$
2.2	0.2	1.40	0.0092	3.0	0.2	0.75	0.0059
	0.4	2.70	0.0170		0.4	1.50	0.0105
	0.6	3.90	0.0243		0.6	2.25	0.0152
	0.8	4.98	0.0310		0.8	3.00	0.0199
	1.0	6.02	0.0375		1.0	3.75	0.0241
	1.2	7.03	0.0432		1.2	4.50	0.0282
	1.4	8.00	0.0482		1.4	5.25	0.0325
	1.6	8.92	0.0530		1.6	6.00	0.0369
	1.8	9.82	0.0573		1.8	6.75	0.0410
	2.0	10.69	0.0615		2.0	7.50	0.0449
	2.2	11.48	0.0655		2.2	8.25	0.0488
2.4	0.2	1.22	0.0082	3.2	0.2	0.70	0.0052
	0.4	2.30	0.0145		0.4	1.40	0.0095
	0.6	3.32	0.0205		0.6	2.09	0.0140
	0.8	4.30	0.0263		0.8	2.78	0.0185
	1.0	5.28	0.0319		1.0	3.48	0.0227
	1.2	6.23	0.0372		1.2	4.18	0.0265
	1.4	7.13	0.0425		1.4	4.87	0.0302
	1.6	8.00	0.0473		1.6	5.57	0.0342
	1.8	8.83	0.0520		1.8	6.26	0.0379
	2.0	9.60	0.0563		2.0	6.96	0.0418
	2.2	10.32	0.0602		2.2	7.66	0.0455
2.6	0.2	1.03	0.0072	3.4	0.2	0.65	0.0045
	0.4	2.00	0.0122		0.4	1.30	0.0088
	0.6	2.90	0.0182		0.6	1.96	0.0129
	0.8	3.78	0.0237		0.8	2.61	0.0169
	1.0	4.63	0.0289		1.0	3.26	0.0209
	1.2	5.50	0.0338		1.2	3.91	0.0245
	1.4	6.35	0.0385		1.4	4.56	0.0282
	1.6	7.20	0.0433		1.6	5.22	0.0319
	1.8	8.03	0.0478		1.8	5.87	0.0352
	2.0	8.80	0.0523		2.0	6.52	0.0388
	2.2	9.50	0.0568		2.2	7.17	0.0420
2.8	0.2	0.83	0.0066	3.6	0.2	0.60	0.0040
	0.4	1.66	0.0115		0.4	1.20	0.0078
	0.6	2.50	0.0168		0.6	1.80	0.0118
	0.8	3.33	0.0219		0.8	2.40	0.0158
	1.0	4.16	0.0257		1.0	3.00	0.0192
	1.2	4.99	0.0312		1.2	3.60	0.0225
	1.4	5.82	0.0359		1.4	4.20	0.0258
	1.6	6.66	0.0402		1.6	4.80	0.0292
	1.8	7.49	0.0445		1.8	5.40	0.0323
	2.0	8.32	0.0488		2.0	6.00	0.0355
	2.2	9.15	0.0531		2.2	6.60	0.0387

TABLE VIII (Cont)

J	C_p	ϕ	$\Delta V/V$
3.8	0.2	0.56	0.0033
	0.4	1.12	0.0068
	0.6	1.68	0.0103
	0.8	2.24	0.0137
	1.0	2.80	0.0170
	1.2	3.36	0.0200
	1.4	3.92	0.0232
	1.6	4.48	0.0263
	1.8	5.04	0.0292
	2.0	5.60	0.0320
	2.2	6.16	0.0345
4.2	0.2	0.46	0.0028
	0.4	0.93	0.0062
	0.6	1.39	0.0095
	0.8	1.86	0.0125
	1.0	2.32	0.0155
	1.2	2.78	0.0182
	1.4	3.25	0.0210
	1.6	3.71	0.0238
	1.8	4.18	0.0263
	2.0	4.64	0.0285
	2.2	5.10	0.0308
4.6	0.2	0.40	0.0024
	0.4	0.79	0.0052
	0.6	1.19	0.0080
	0.8	1.58	0.0108
	1.0	1.98	0.0132
	1.2	2.38	0.0155
	1.4	2.77	0.0182
	1.6	3.17	0.0203
	1.8	3.56	0.0223
	2.0	3.96	0.0243
	2.2	4.36	0.0262

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PROP-FAN AND GEARBOX

NEAR-FIELD NOISE PREDICTIONS

October 31, 1977

PROP-FAN NEAR-FIELD NOISE ESTIMATION AT CRUISE

The attached noise generalization is for six, eight, and ten-bladed Prop-Fans. It allows estimation of free field overall noise level and spectrum level at near-field locations where an aircraft fuselage would be located. Noise can be estimated at forward speeds of 0.7 to 0.8 Mach number, tip speeds from 600 to 800 ft/sec (183 to 244 m/sec) at cruise altitudes from 30,000 to 45,000 feet (9144 to 13716 m). The levels fore and aft of the peak noise location near the plane of rotation are presented for tip clearances (the distance from the fuselage to the propeller tip) from 0.2 to 0.8 propeller diameters.

The near-field noise prediction procedure is based on calculations made with the theoretical Prop-Fan prediction procedure developed by Hamilton Standard. The computer results have been generalized for an advanced Prop-Fan configuration to indicate the level of noise expected for a fully developed Prop-Fan.

Near-field noise generated by a Prop-Fan may be estimated as follows:

1. For the design rotational tip speed and cruise Mach number, determine the efficiency, η , from the Prop-Fan performance procedure.

2. Determine the maximum sideline overall sound pressure level at 0.8 diameters from the Prop-Fan tip, from Figure 1 for a six-blade fan, Figure 2 for an eight-blade fan or Figure 3 for a ten-blade fan.

3. If the altitude differs from 30,000 feet (9144) the altitude correction from Figure 4 should be added to the base level from Figures 1, 2, or 3.

4. If the noise at a measurement point fore and aft of the peak, or a tip clearance of other than 0.8 diameter is to be estimated, add the partial levels from Figures 5, 6, or 7 to the base levels from Figures 1, 2, or 3. These figures were derived from calculations at 0.7 Mach number cruise at 35,000 feet (10,668 m) altitude but may be applied for any other cruise condition.

5. The spectrum level relative to the overall levels determined by the above steps is found in Figure 8. This figure was derived from calculations at 0.7 Mach number cruise at 35,000 foot (10,668 m) altitude but may be applied for any other cruise condition.

SAMPLE ESTIMATE OF PROP-FAN NEAR-FIELD NOISE

To assist those using the Prop-Fan near-field noise generalization, the following sample calculation is provided:

. Efficiency:	0.83 (from the Prop-Fan performance procedure)
. Tip Speed:	800 ft/sec (244 m/sec)
. Cruise Mach Number:	0.8
. Tip Clearance:	0.4 Diameter
. Fore and Aft Location:	0.5 Diameter Forward
. Altitude:	35,000 feet (10,668 m)
. Number of Blades:	Ten

Step 1: For an efficiency of 0.83, a tip speed of 800 ft/sec (244 m/sec), a cruise Mach number of 0.8, and ten blades in the fan; Figure 3 indicates that the peak sideline overall sound pressure level is 135.0 dB.

Step 2: Since the operating altitude is 35,000 ft (10,668 m) the noise level of Step 1 is reduced by 2 dB on the basis of Figure 4.

Step 3: For a tip clearance of 0.4 diameter and a fore and aft distance of 0.5 diameter forward for a ten-blade fan; Figure 7 indicates that the level in Step 1 is reduced by 2 1 dB.

Step 4: The overall sound pressure level is the sum of the partial levels of Steps 1, 2, and 3; 135 - 2 - 21 = 112.0 dB.

Step 5: For a tip speed of 800 ft/sec (244 m/sec) the spectrum level corrections from Figure 8 are:

	Level Relative to Overall Sound Pressure Level	Sound Pressure Level of Blade Passage Frequency Harmonics
Blade Passage Frequency (BPF)	-1.5 dB	110.5 dB
2X BPF	-8.5	103.5
3X BPF	-15.5	96.5
4X BPF	-20	92
5X BPF	-22	90
6X BPF	-23	89
7X BPF	-23	89
8X BPF	-23.5	88.5
9X BPF		
10X BPF		
11X BPF		
12X BPF		
13X BPF		
14X BPF		

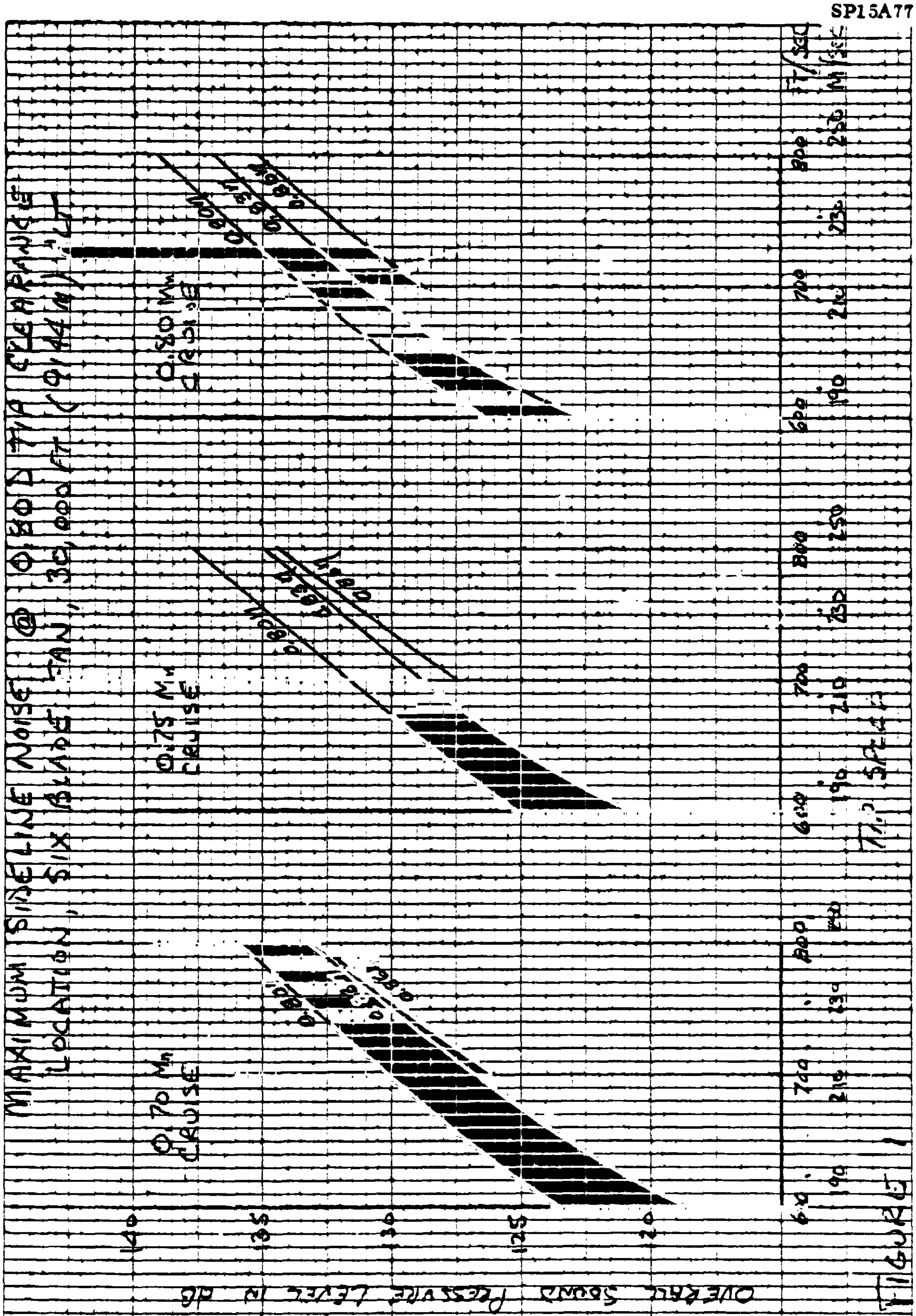
MAXIMUM SIDELINE NOISE @ 0.800 TIP CLEARANCE
LOCATION, SIX BLADE FAN, 30,000 FT (9144 M) "L"
0.70 Mn CRUISE
0.75 Mn CRUISE
0.80 Mn CRUISE
OVERALL SOUND PRESSURE LEVEL IN dB
140
135
130
125
120
600
700
800
FT/SEC
190
210
230
250
M/SEC
TIP SPEED

FIGURE 1

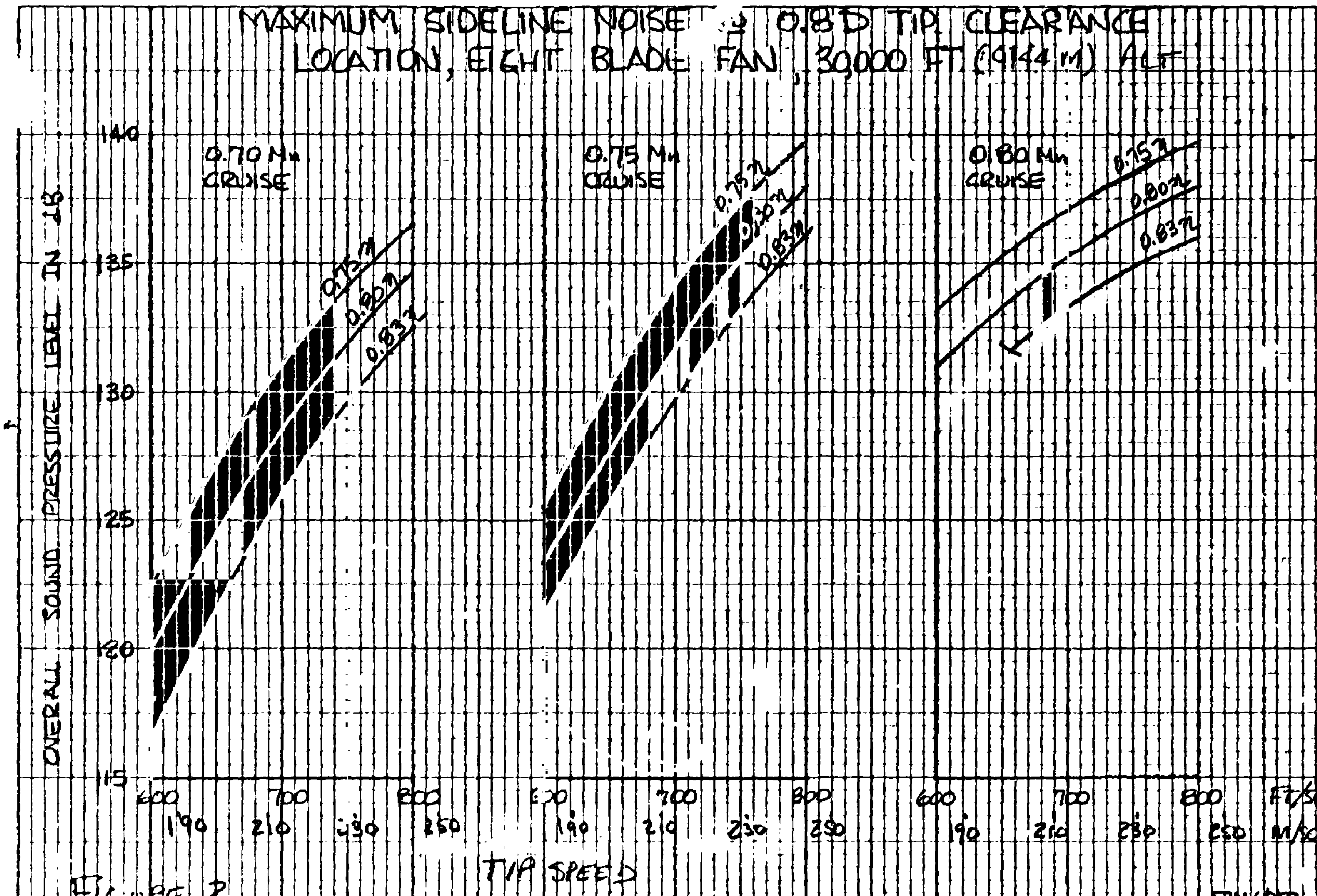

FIGURE 2

CALC. NO. 2837 (25)
SP15A77
FBM 6/77
SGL

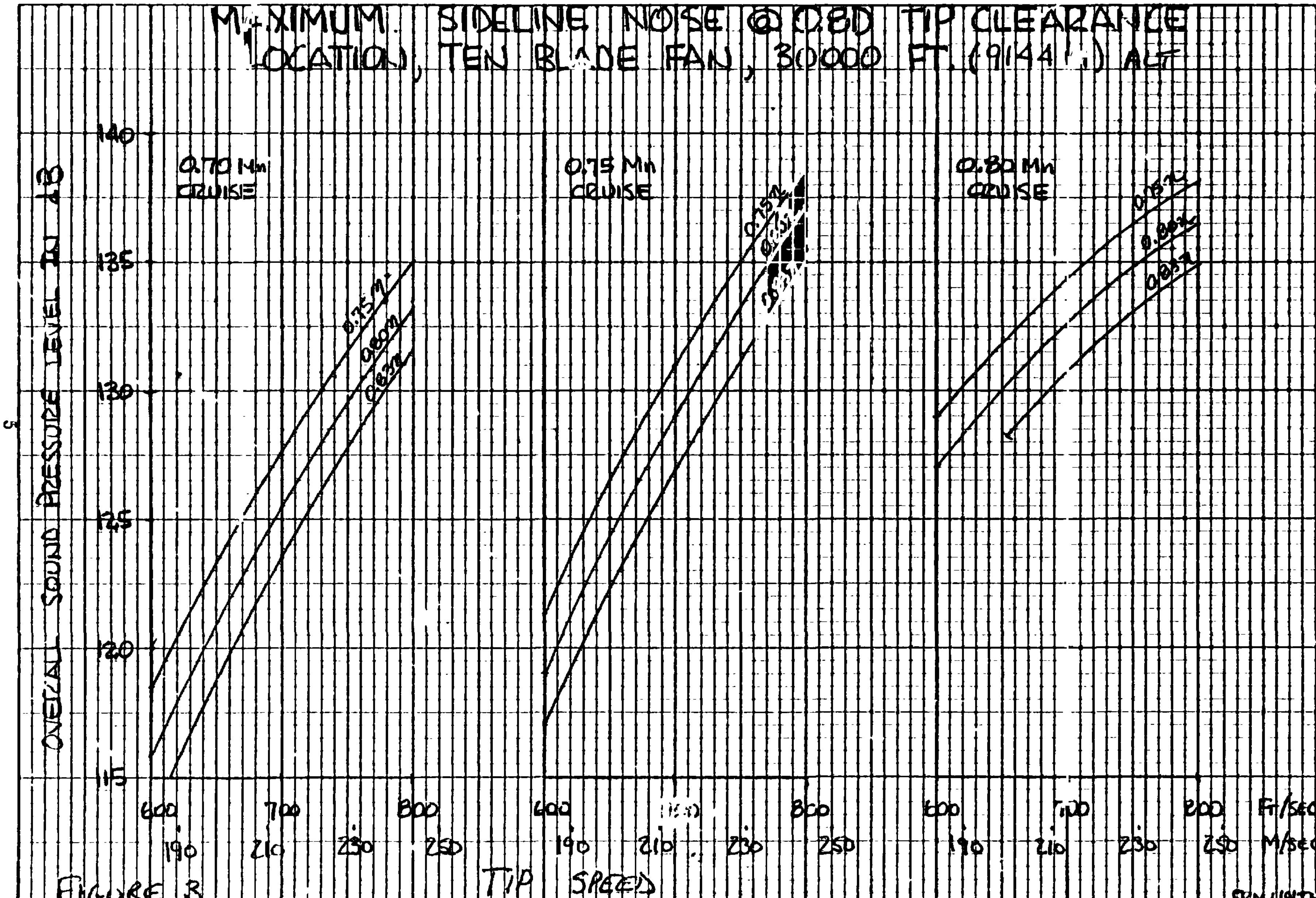

FIGURE 3.

CALC.
SP15A77

CORRECTION FOR THE INFLUENCE
OF ALTITUDE ON NEAR-FIELD CRUISE NOISE LEVEL

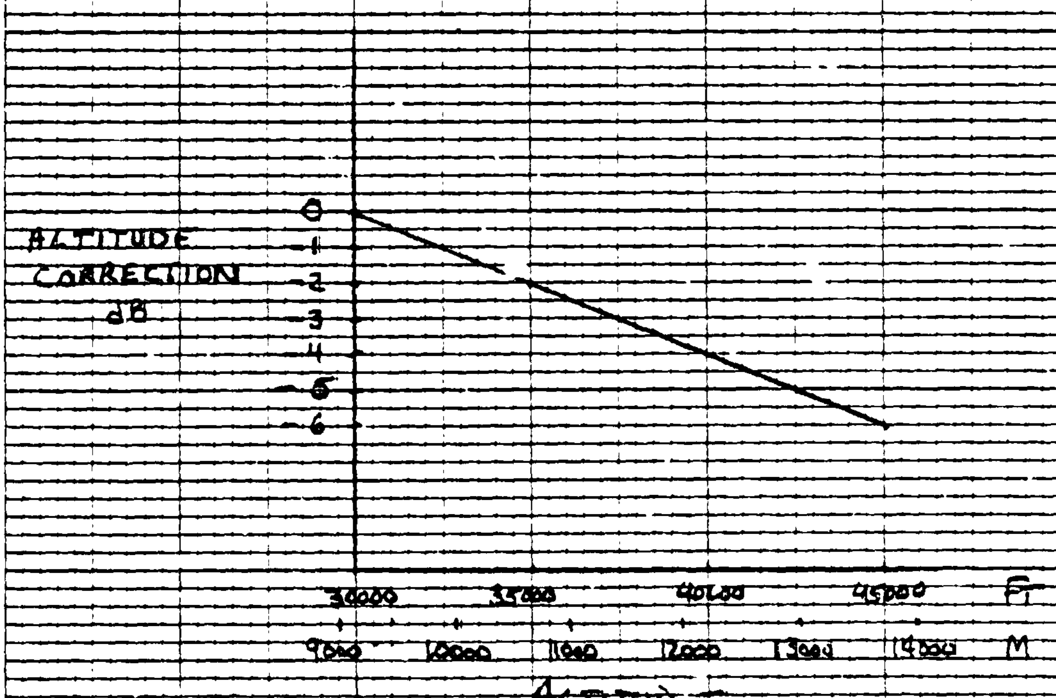

FIGURE 4

NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

DIETZGEN CORPORATION
MADE IN U.S.A.

ORIGINAL PAGE IS
OF POOR QUALITY

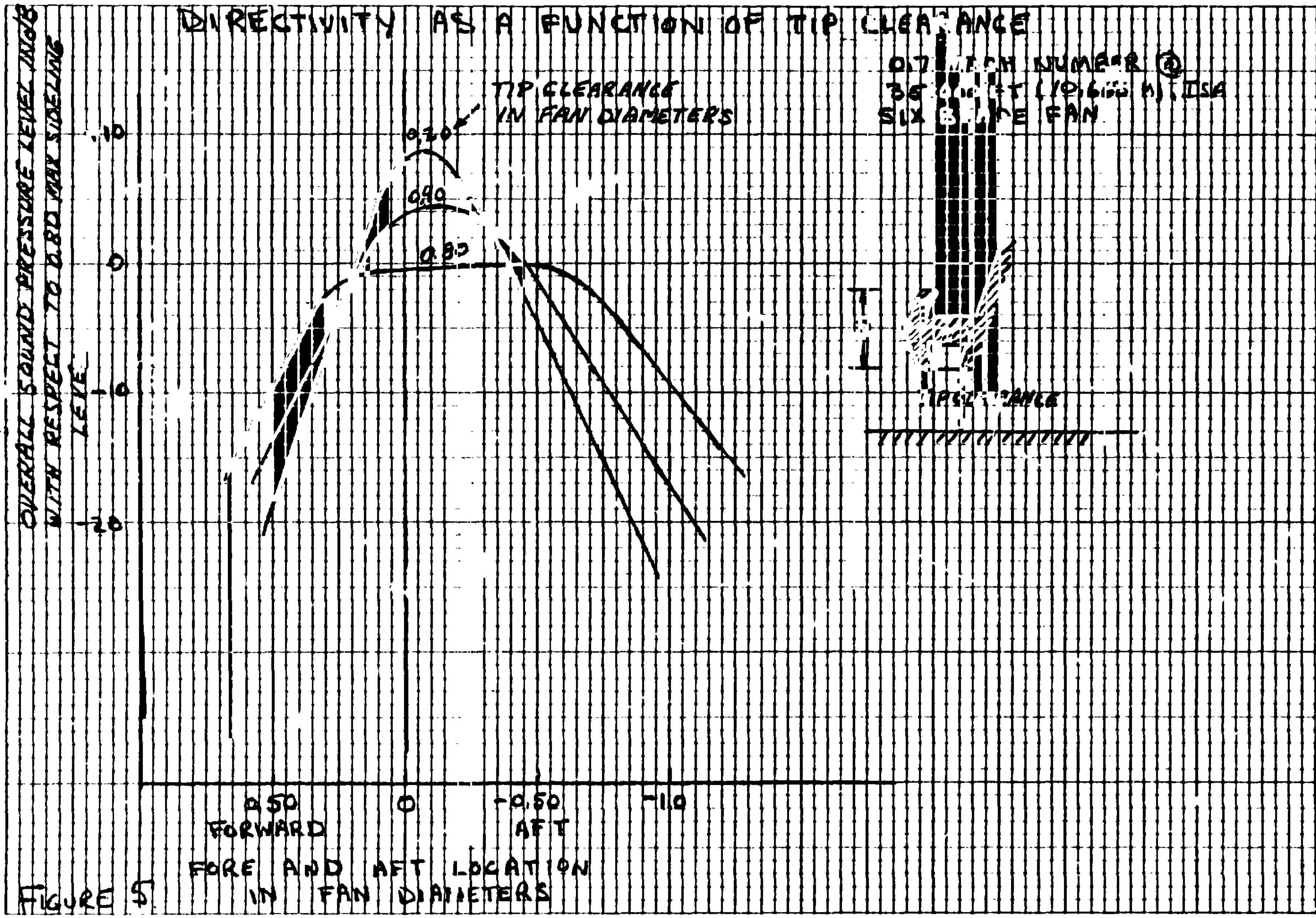

FIGURE 5

CALC NO 2880(1) SP15A77
Revision 6
2/28/78

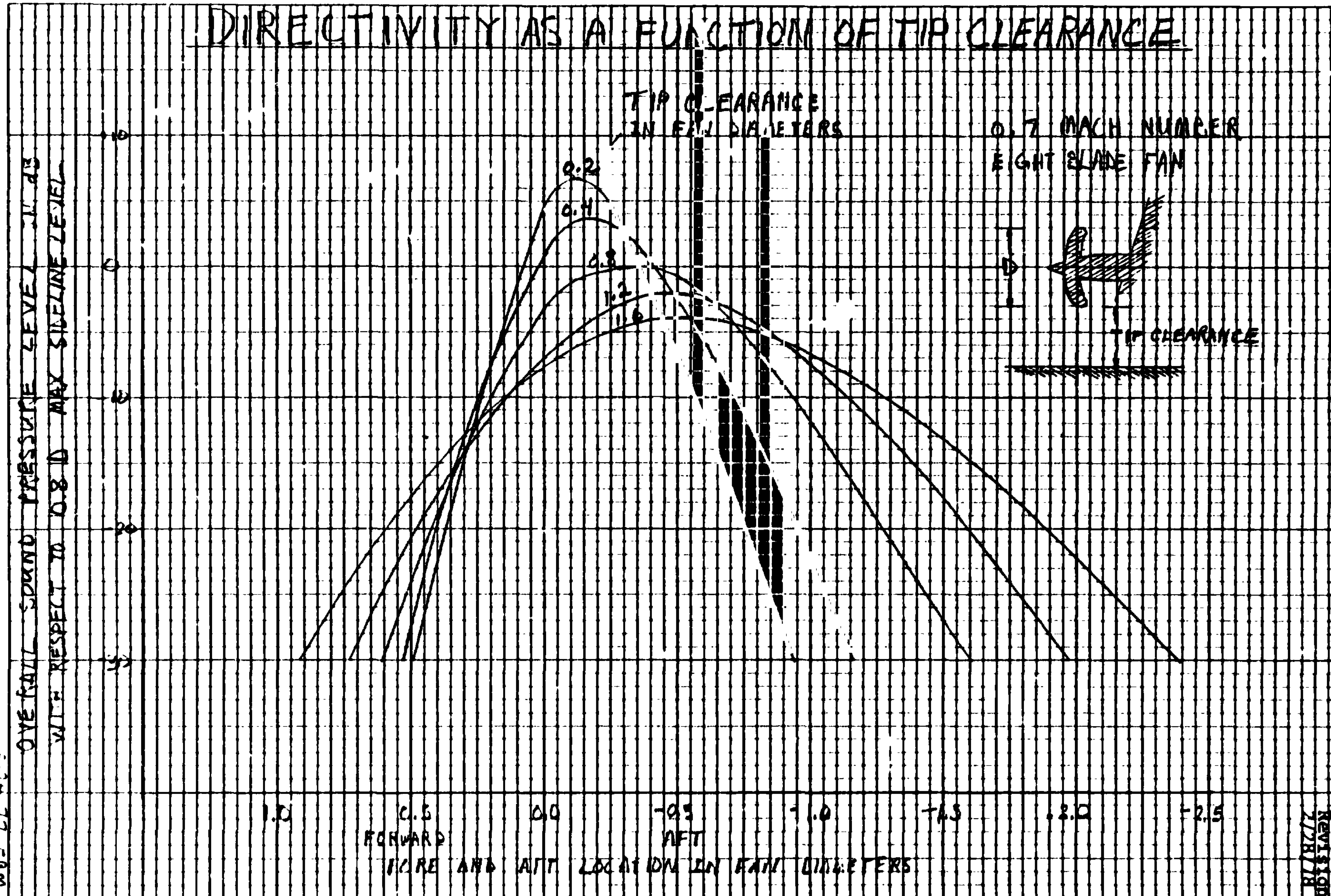

FIGURE 6.

5-24-77 FBM
REVISED 6-9-77 SGK
REVISED 12-14-77 GJM

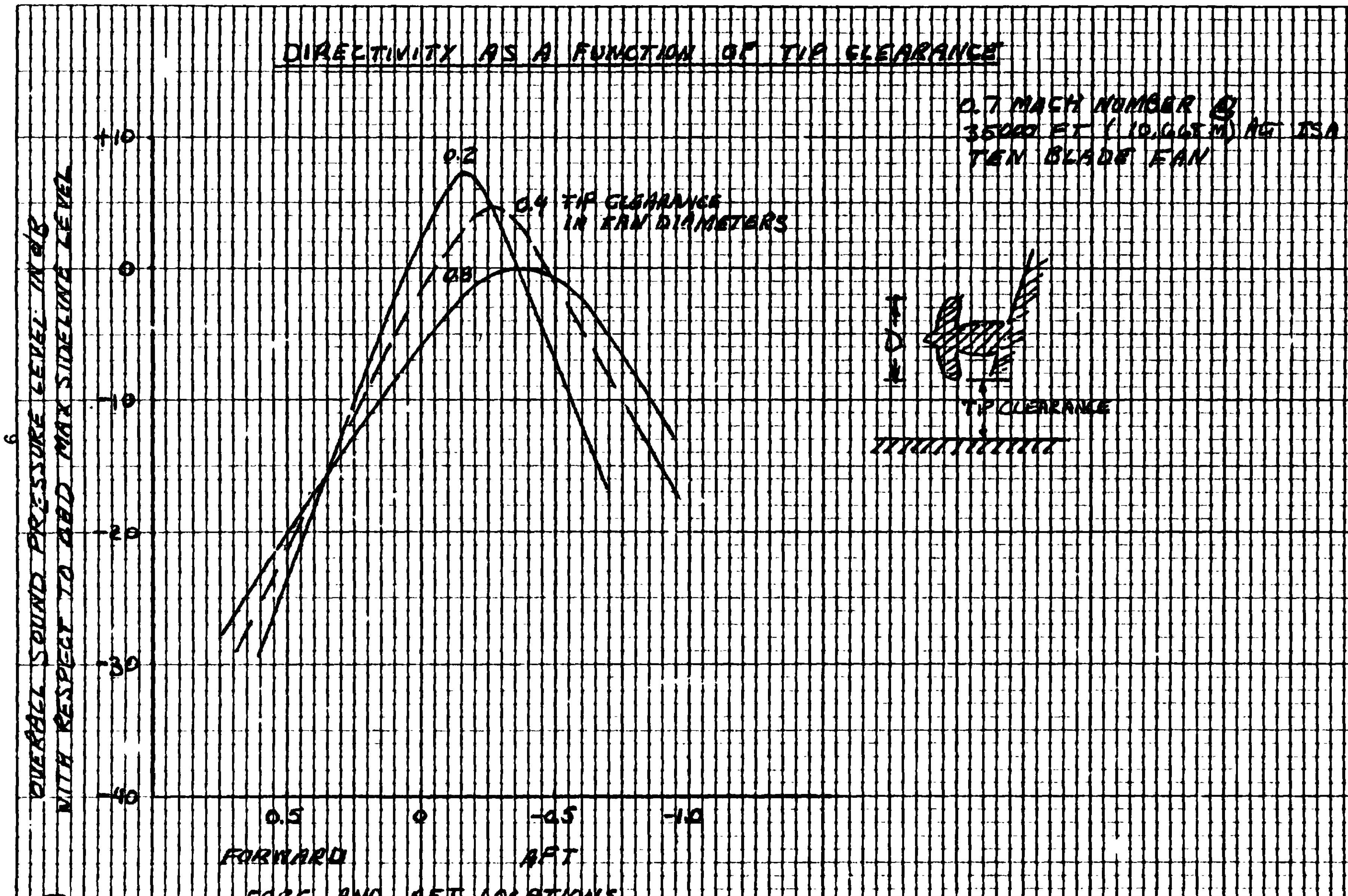
DIRECTIVITY AS A FUNCTION OF TIP CLEARANCE
0.7 MACH NUMBER @
35000 FT (10,668 M) AG ISA
TEN BLADE FAN
0.2
0.4 TIP CLEARANCE
IN FAN DIAMETERS
0.8
D
TIP CLEARANCE
OVERALL SOUND PRESSURE LEVEL IN dB
WITH RESPECT TO 0 dB MAX SIDELINE LEVEL
+10
0
-10
-20
-30
-40
0.5
0
-0.5
-1.0
FORWARD
AFT
FORE AND AFT LOCATIONS
IN FAN DIAMETERS

Figure 7

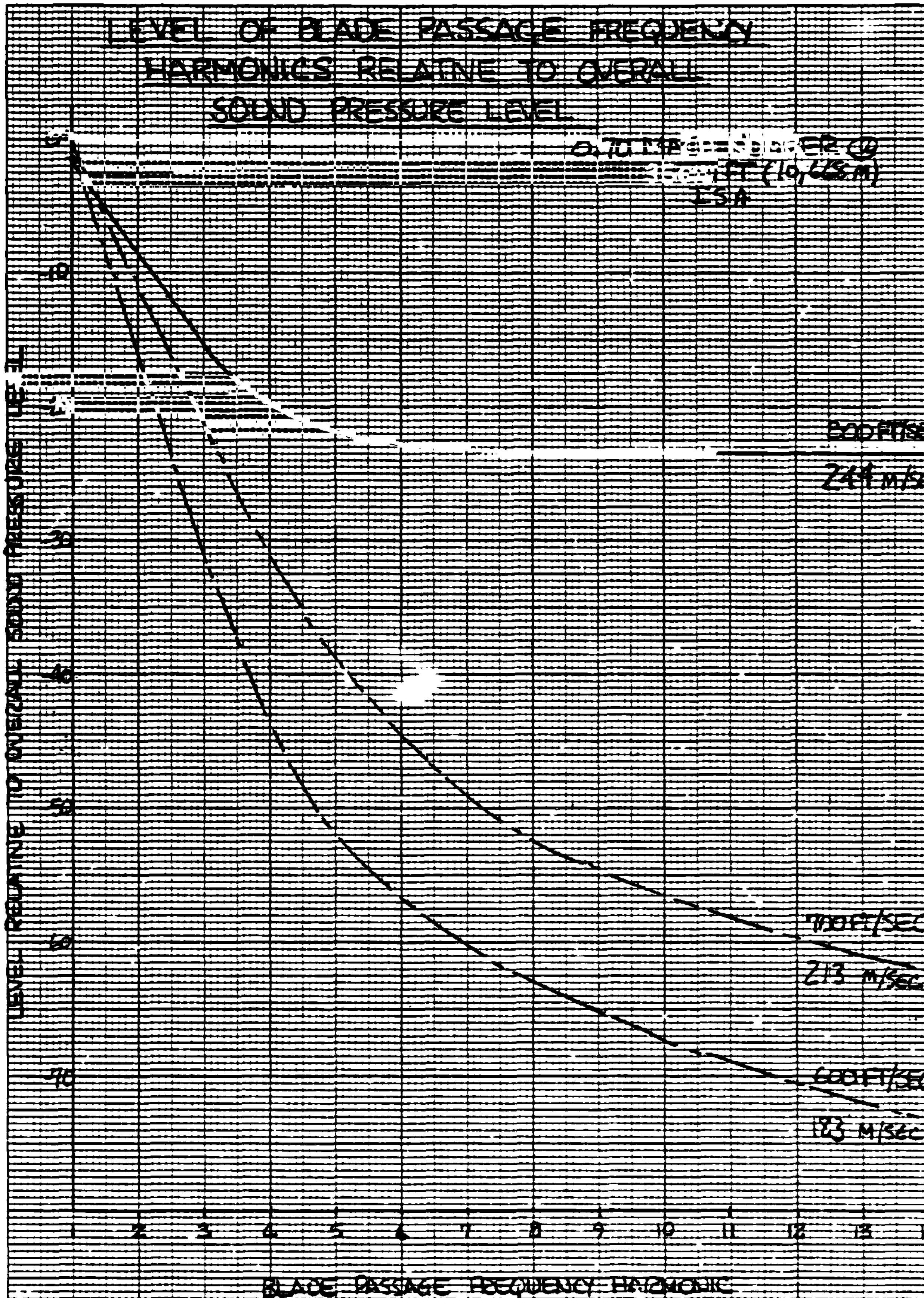

FIGURE 8

NO. 340-20 DIETZGEN GRAPH PAPER 20 X 20 PER INCH

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5-24-77 FBM
REVISED
6-8-77 SGK

Prop-Fan Gearbox Noise Estimation

The attached noise generalization allows estimation of the uninstalled gearbox noise (i.e. without additional attenuation from enclosing nacelles) associated with a Prop-Fan Propulsion System. This procedure is derived from a procedure developed by Hamilton Standard and published in FAA report FAA-RD-76-49, II, entitled V/STOL Rotary Propulsion Systems Noise Prediction and Reduction. The absolute accuracy of the method has not been established by correlation studies with test data since there is little test data available on installed gearboxes. However, the method should be adequate for preliminary design studies of Prop-Fan systems.

The noise generated by gearboxes used in Prop-Fan aircraft propulsion systems may be estimated using the procedure presented below.

The required information includes:

1. Power transmitted per stage.
2. The input or output gear rate of revolution and number of teeth.

The noise estimate is made by computing a 1/3 octave band spectrum of the noise for each stage, then summing the spectra logarithmically.

The noise spectrum from one gearbox stage may be estimated as follows:

Step 1. Obtain the overall Sound Pressure Level from the following equation based on transmitted horsepower, distance from gearbox to measurement location and ambient conditions.

$$SPL = 18 \log_{10} HP - 20 \log_{10} R + 10 \log_{10} P - 5 \log_{10} T + K$$

where:
- SPL = Sound Pressure Level, dB re 20 μPa
- HP = Transmitted power
- R = Source-to-observer distance
- P = The ambient pressure
- T = The ambient temperature
- K = 67.4 for units in horsepower, feet, psia, and ^{o}R
  19.9 for units in KW, meters, N/m^2, and ^{o}K

Step 2. Calculate the tooth contact frequency, f_{T_C}, from:

$$f_{T_C} = RPS \times N$$

where RPS x N is the revolution/sec x no. of teeth of either input or output gear

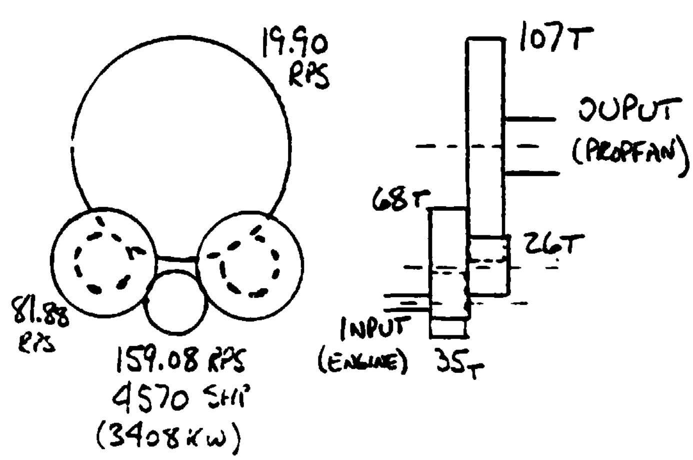
Step 3. Calculate the reference frequency as the center frequency of the 1/3 octave band containing the tooth contact frequency, f_{T_C}. Obtain the spectrum correction, from Figure 9. The short vertical lines just above the horizontal axis indicates 1/3 octave band frequency above and below that containing the tooth contact frequency (at a frequency ratio of 1).

Step 4. The algebraic sum of the Overall Sound Pressure Level from Step 1 and the spectrum correction from figure 9 gives the gearbox 1/3 octave band Sound Pressure Levels.

Step 5. If the gearbox has more than one stage repeat the above steps for each stage and sum the noise contributions of the stages logarithmically.

Sample Estimate of Gearbox Noise

To assist those using the Prop-Fan Gearbox Near Field Noise Generalization the following sample calculation is provided:



Distance= 1.2D + .8D =1.3D
= 1.3x11 ft =14.3 ft (4.36m)

At 35,000 ft (10,668m) altitude:
P= 3.47 PSIA (23,923 N/m^2)
T= 394°R (234°K)

Since the load is shared by the two intermediate stages, they will be considered as two independent stages transmitting one half the power. Thus:

Step 1.

$$SPL = 18 \log_{10}\left\{\frac{4570}{2}\right\} -20 \log_{10} (14.3) + 10 \log_{10} (3.47) -5 \log_{10} (394) + 67.4$$

$= 97$ dB

OR

$$SPL = 18 \log_{10}\left\{\frac{3408}{2}\right\} -20 \log_{10} (4.36) + 10 \log_{10} (23923) -5 \log_{10} (234) + 19.9$$

$= 97$ dB

Since there are two parallel stages, the SPL will be 3 dB higher, or 100 dB per reduction stage.

Step 2. 1st stage f_{T_c} = 159.08 x 35 / 60 = 5568 Hz

2nd stage f_{T_c} = 19.90 x 107 / 60 = 2129 Hz

Step 3. The first stage f_{T_c} is in the 5000 Hz band and the second stage f_{T_c} is in the 2000 Hz band.

Step 4.& 5. Using figure 9 the spectra for the two stages are thus:

1/3 Octave Band	SPL_1	SPL_2	Total
630 Hz		70 dB	70 dB
800		72	72
1000		74	74
1250		75	75
1600	70 dB	82	82
2000	72	95	95
2500	74	90	90
3150	75	83	84
4000	82	95	95
5000	95	85	95
6300	90	86	92
8000	83	88	89
10000	95	75	95

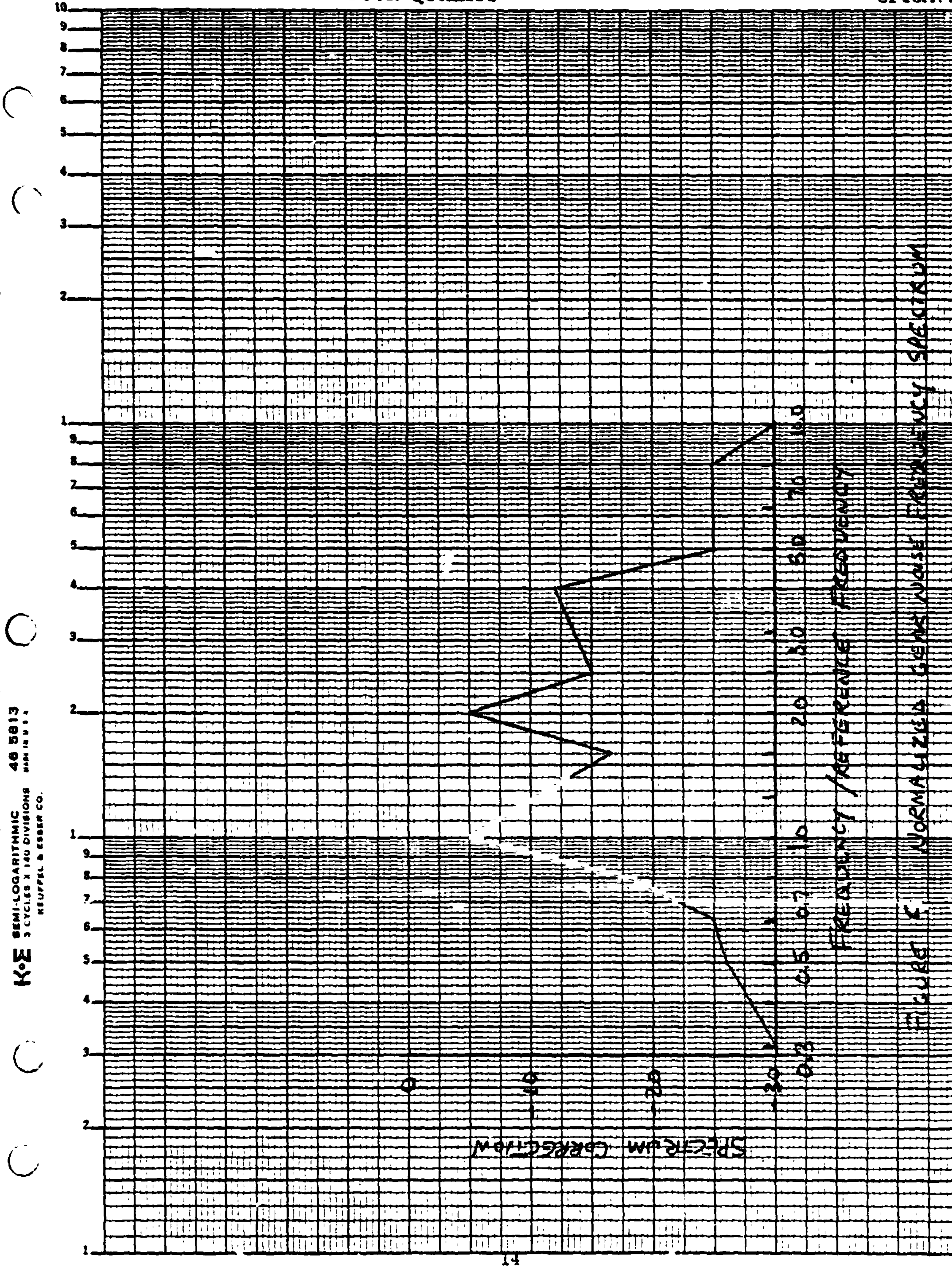


FIGURE 5. NORMALIZED GEN NOISE FREQUENCY SPECTRUM
FREQUENCY/REFERENCE FREQUENCY
0.3 0.5 0.7 1.0 2.0 3.0 5.0 7.0 10.0
SPECTRUM CORRECTION
0 -10 -20 -30
K•E SEMI-LOGARITHMIC 46 5813
3 CYCLES X 140 DIVISIONS
KEUFFEL & ESSER CO.

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SP16A77
Revision A
2/28/78

PROP-FAN FAR-FIELD NOISE PREDICTIONS

October 31, 1977

PROP-FAN FAR-FIELD NOISE ESTIMATION AT TAKE-OFF AND LANDING

The attached noise generalization is for six, eight and ten-bladed Prop-Fans. It allows estimation of the maximum flyover or sideline Perceived Noise Level for landing and take-off conditions. The procedure does not include core engine noise. For a complete system noise estimate, it is recommended that the core engine noise obtainable from engine manufacturers be included.

The far-field generalization is based on past experience with conventional propellers and incorporates improvements to account for recent propellers designed with both low noise and good performance as a requirement. Based on the available test data, which includes limited tests of the first two Prop-Fan designs, it appears that the levels predicted by the attached method can be achieved. A long range program is now under way to investigate the mechanisms of noise generation and the possibility for reductions relative to the levels predicted by the attached method. The potential for reduction in far-field noise has been conservatively established at 5PNdB. This reduction will be achieved primarily by reducing low frequency steady loading tone noise and to a lesser extent, controlling higher frequency broadband and unsteady loading noise components.

FAR-FIELD PROP-FAN NOISE LEVEL AT TAKE-OFF AND LANDING

Far-field noise generated by a Prop-Fan may be estimated as follows:

1. Determine the rotational tip Mach number by calculation or from Figures 1 and 2.

2. Obtain FL1 from Figure 3. This is a partial level based on the power input to the propeller and its rotational tip Mach number.

3. Obtain the distance correction FL2 from Figure 4. Note that on take-off the distance is that from the measurement location to the aircraft. Thus, for estimates under the take-off path the vertical distance is used. For the sideline certification, the distance may be assumed to be distance from the runway centerline to the measurement location.

4. The Perceived Noise Level adjustment FL3 is obtained from Figure 5. The helical tip Mach number is determined in Figures 2 and 6 using the tip speed (determined in Step 1) plus the forward speed of the aircraft.

5. Apply the following corrections, NC, for number of Prop-Fans:

- One Prop-Fan - add 0
- Two Prop-Fans - add 3
- Three Prop-Fans - add 4.8
- Four Prop-Fans - add 6.

6. The maximum Perceived Noise Level is the sum of FL1, FL2, FL3, and NC.

7. To estimate Effective Perceived Noise Level, subtract 2 dB for take-off or 4 dB for landing from Perceived Noise Level estimates of Step 6.

SAMPLE ESTIMATE OF FAR-FIELD NOISE

To assist those using the Prop-Fan far-field noise generalization, the following sample calculation is provided:

. Diameter:	13.75 feet (4.2 m)
. Power:	14,500 SHP (10,813 kw)
. RPM:	1,042
. Distance:	1,000 feet (304.8 m)
. Aircraft Speed:	180 knots true (333.5 km/hr)
. Temperature:	75°F at altitude
. Number of Prop-Fans:	Four

Step 1:

From Figure 1 - tip speed = 750 ft/sec. (228.6 m/sec)
From Figure 2 - Mach number = 0.66.

Step 2:

From Figure 3 - FL1 = 105

Step 3:

From Figure 4 - FL2 = -7

Step 4:

From Figure 6 - Helical Tip Speed = 810 ft/sec (246.9 m/sec)
From Figure 2 - Helical Tip Mach Number = 0.715
From Figure 5 - FL3 = -5

Step 5:

For four Prop-Fans - NC = +6

Step 6:

Perceived Noise Level (FL1 + FL2 + FL3 + NC) = 99 PNdb.

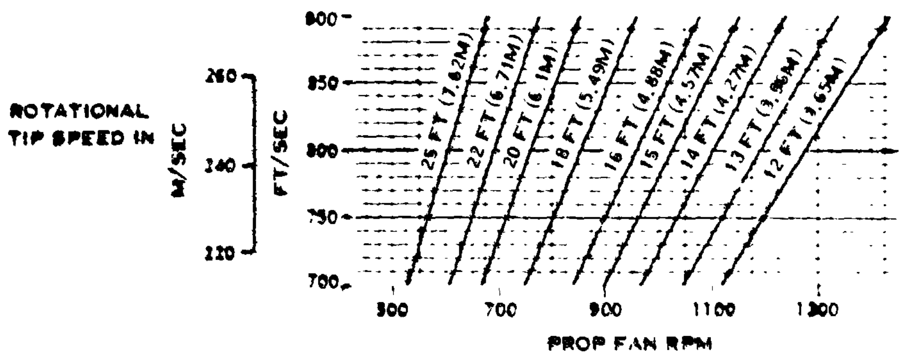


FIGURE RPM TO TIP SPEED CONVERSION

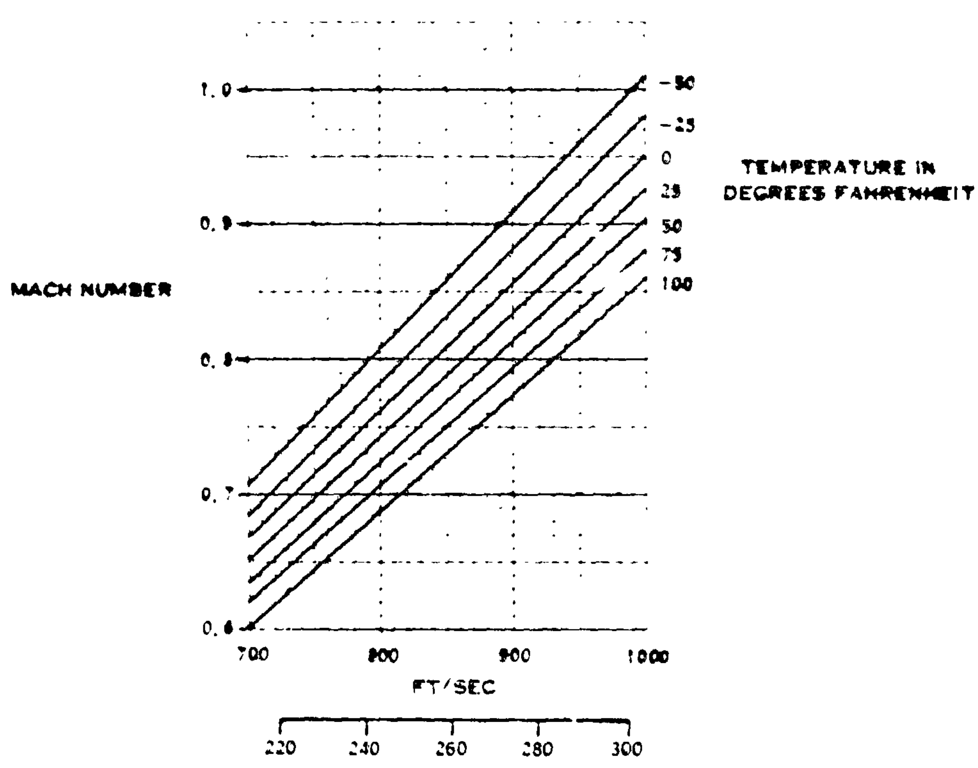


FIGURE 2. TIP SPEED TO MACH NUMBER CONVERSION

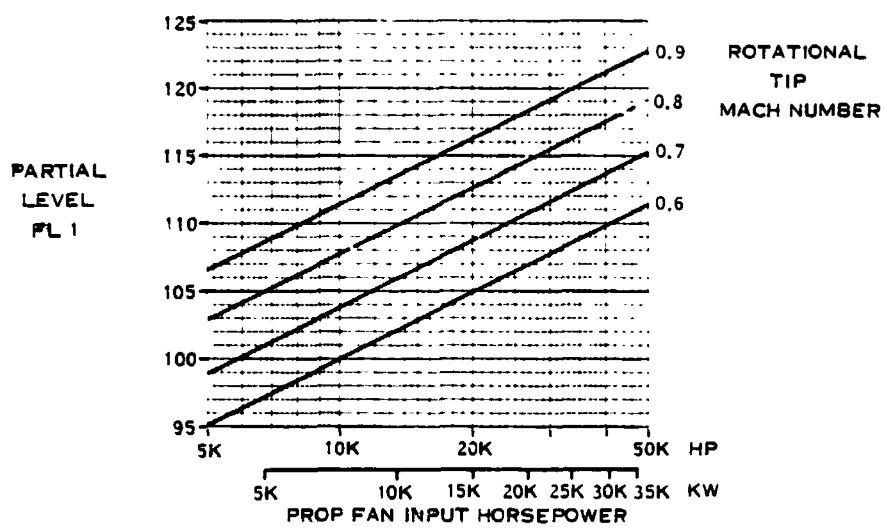


FIGURE 3. FAR FIELD PARTIAL LEVEL BASED ON POWER AND ROTATIONAL TIP MACH NUMBER

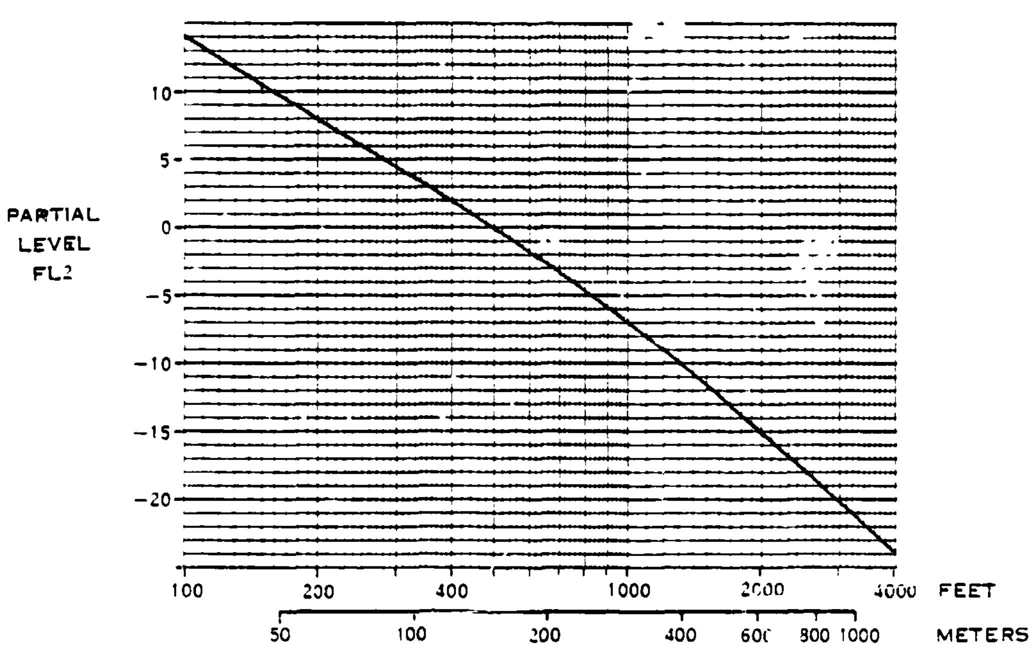


FIGURE 4. PERCEIVED NOISE LEVEL DISTANCE CORRECTION

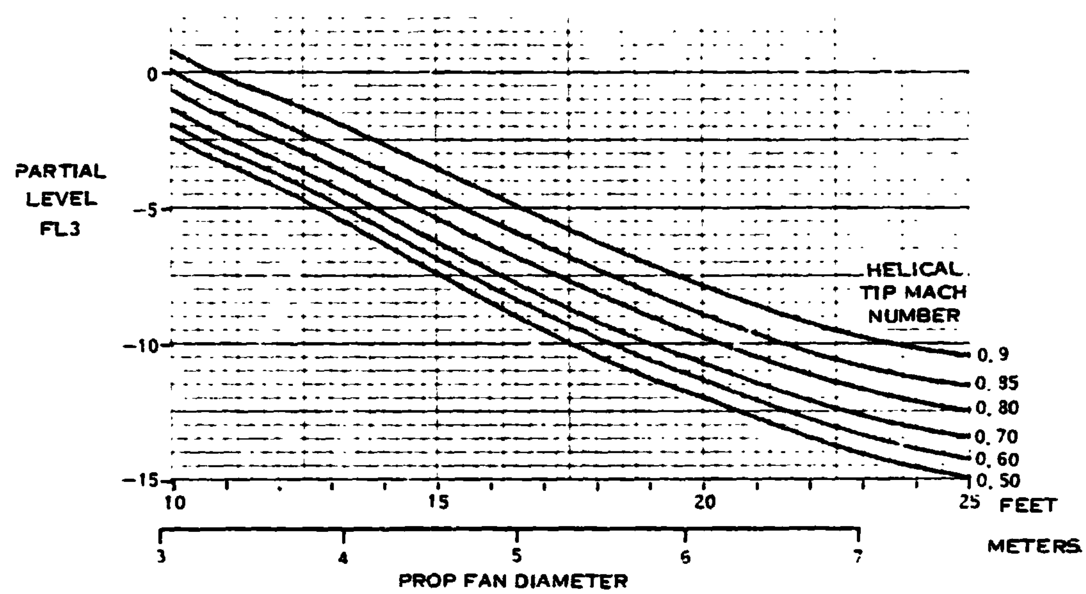


FIGURE 5 PERCEIVED NOISE LEVEL ADJUSTMENT

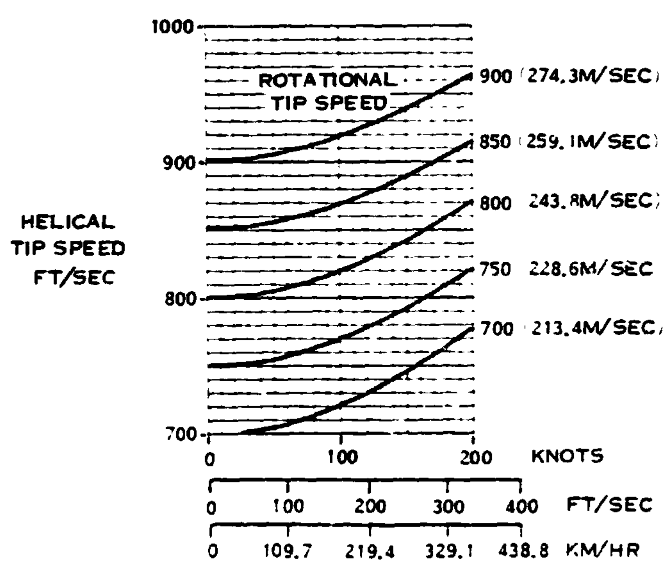


FIGURE 6. PROP FAN HELICAL TIP SPEED

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SP18A77

PROP-FAN WEIGHT ESTIMATION

FOR THE

EIGHT (8) BLADE PROP-FAN CONFIGURATION AND GEARBOX

October 31, 1977

PROP-FAN WEIGHT ESTIMATION

The attached curves provide weight estimates for a Prop-Fan (high speed turboprop and gearbox system) designed for a 0.8 Mach No. cruise aircraft. The technology level included is appropriate for Prop-Fan systems expected to be in-service in the 1985-1990 time period.

The power loading (SHP/D^2) term used on the rotor weight curve in Figure 1 is based on the maximum power delivered to the rotor. The tip speed (TS) that should be used for rotor weights is that at which the maximum SHP occurs. The weight curve in Figure 1 is plotted for a tip speed of 800 ft/sec. Rotor weights for other tip speeds can be obtained by utilizing the conversion formula provided in the curve notes. Figure 2 shows a curve of gearbox weight as a function of the maximum delivered output torque. The curve is based on a total gear ratio of 8:1. Gearbox weights for other gear ratios can be obtained from the conversion formula provided on the curve.

The curves provide uninstalled rotor and gearbox weight estimates and the major components included are defined on the curves. An assessment has been made of the additional components and weight required for a fully installed Prop-Fan propulsion nacelle package. The additional components included:

- Nacelle cowling and fairings
- Nacelle structure for attachment to wing
- Engine-to-gearbox coupling structure and shaft
- Engine/gearbox mounting to nacelle structure
- Engine air inlet ducting
- Engine exhaust system
- Fire control system
- Gearbox cooling and oil tankage system
- Engine starting system
- Hydraulic system and hydraulic fluid
- Electrical system
- Fuel system
- Pneumatic system
- Engine and Prop-Fan control linkage

It is estimated that the fully installed Prop-Fan propulsion nacelle package (Prop-Fan rotor and gearbox, turboshaft engine and above listed additional components) would weigh 1.3 times the sum of the rotor, gearbox and engine weight. This factor is based on a turboshaft engine weight of 0.167 lbs. per SHP (0.101 Kg per Kw).

Sample Weight Calculations:

Rotor:

Given: Diameter, D = 16 ft.

Max. operating horsepower to the Prop-Fan = 17,920

Calculate: $\frac{SHP}{D^2} = \frac{17,920}{(16)^2} = 70$

Rotor weight from Figure 1 is 2375 pounds or 1080 kilograms.

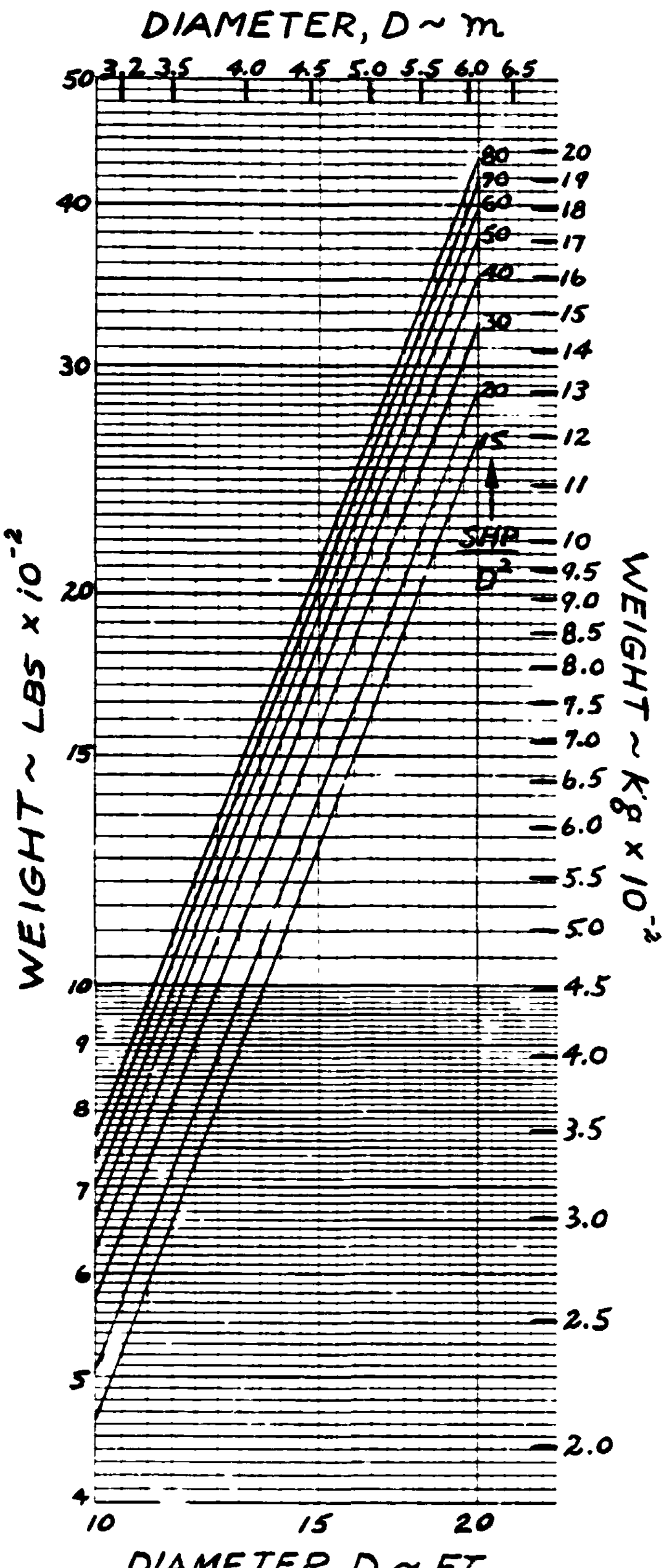
Gearbox:

Calculate: Max. output torque = 4.125 (SHP)(D)

Torque = (4.125)(17,920)(16) = 1.1827×10^6 in-lbs.

Gearbox weight from Figure 2 is 1450 pounds or 658 kilograms.

Note: The above torque equation is based on a tip speed of 800 ft/sec. Modify the torque by 800/TS for other tip speeds.



NOTES:

- WEIGHT INCLUDES:
  - 8 BLADES
  - DISK W/O TAILSHAFT
  - PITCH CHANGE SYSTEM
  - SPINNER
- TIP SPEED, $TS = 800 \frac{ft}{sec}$ OR $244 \frac{m}{sec}$
- WEIGHT AT OTHER VALUES OF TS, WT_{TS}:

$$WT_{TS} = WT_{800}\left[\frac{TS}{800}\right]^{0.3}$$

  WHERE:
  WT_{800} IS WEIGHT FROM THIS CURVE.
  TS IS TIP SPEED OTHER THAN 800 IN ft/sec.
- D IS ROTOR DIAMETER IN FEET OR METERS
- WEIGHT IS IN POUNDS OR KILOGRAMS
- $\frac{SHP}{D^2}$ IS IN $\frac{HP}{FT^2}$

$$1 \frac{HP}{FT^2} = 8.027 \frac{KILOWATT}{METER^2}$$

FIGURE 1. ROTOR WEIGHT vs. DIAMETER FOR 8 BLADES

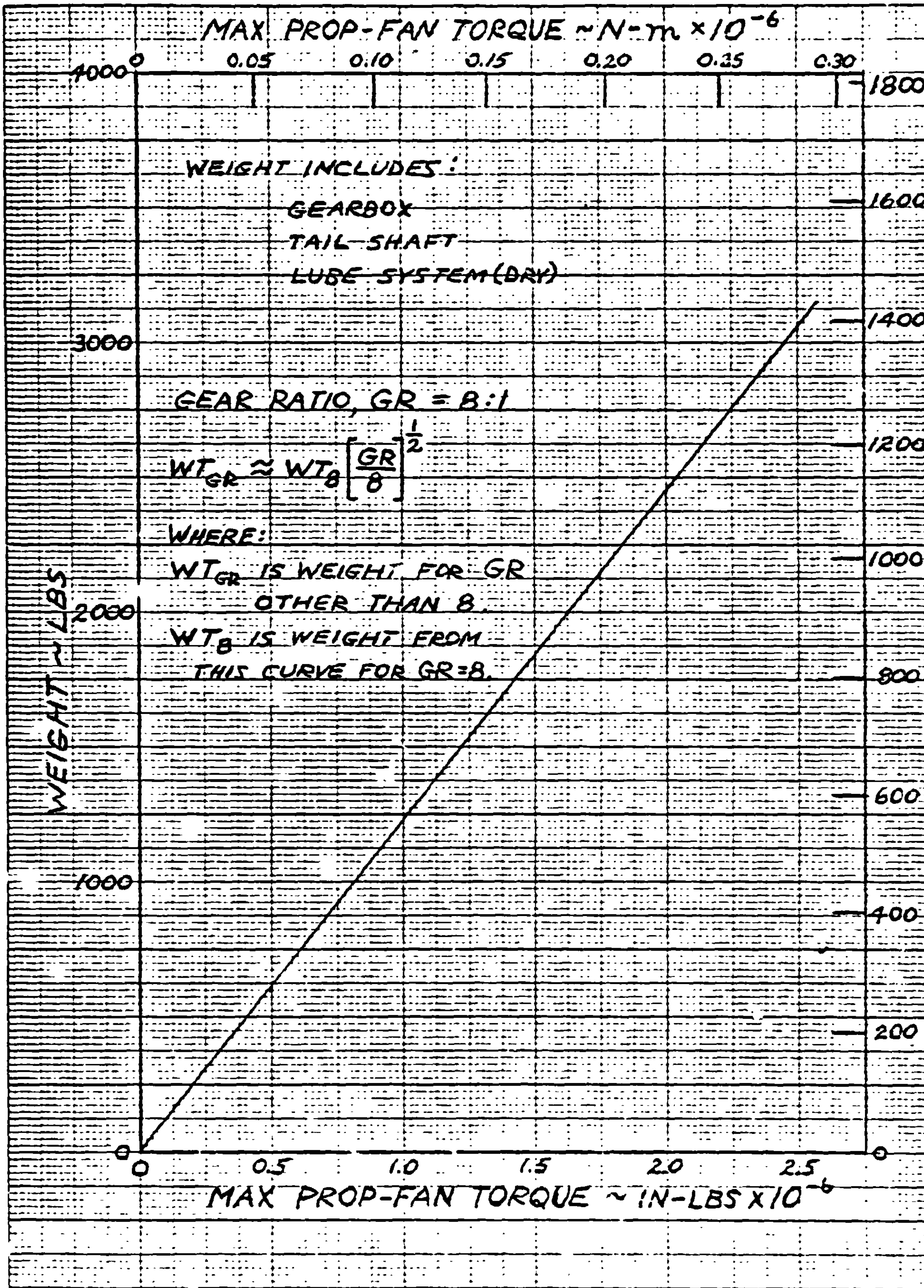


FIGURE 2. GEARBOX WEIGHT vs. PROP-FAN TORQUE

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SP19A77

PROP-FAN WEIGHT ESTIMATION

FOR THE

TEN (10) BLADE PROP-FAN CONFIGURATION AND GEARBOX

October 31, 1977

PROP-FAN WEIGHT ESTIMATION

The attached curves provide weight estimates for a Prop-Fan (high speed turbo-prop and gearbox system) designed for a 0.8 Mach No. cruise aircraft. The technology level included is appropriate for Prop-Fan systems expected to be in-service in the 1985-1990 time period.

The power loading (SHP/D^2) term used on the rotor weight curve in Figure 1 is based on the maximum power delivered to the rotor. The tip speed (TS) that should be used for rotor weights is that at which the maximum SHP occurs. The weight curve in Figure 1 is plotted for a tip speed of 800 ft/sec. Rotor weights for other tip speeds can be obtained by utilizing the conversion formula provided in the curve notes. Figure 2 shows a curve of gearbox weight as a function of the maximum delivered output torque. The curve is based on a total gear ratio of 8:1. Gearbox weights for other gear ratios can be obtained from the conversion formula provided on the curve.

The curves provide uninstalled rotor and gearbox weight estimates and the major components included are defined on the curves. An assessment has been made of the additional components and weight required for a fully installed Prop-Fan propulsion nacelle package. The additional components included:

- Nacelle cowling and fairings
- Nacelle structure for attachment to wing
- Engine-to-gearbox coupling structure and shaft
- Engine/gearbox mounting to nacelle structure
- Engine air inlet ducting
- Engine exhaust system
- Fire control system
- Gearbox cooling and oil tankage system
- Engine starting system
- Hydraulic system and hydraulic fluid
- Electrical system
- Fuel system
- Pneumatic system
- Engine and Prop-Fan control linkage

It is estimated that the fully installed Prop-Fan propulsion nacelle package (Prop-Fan rotor and gearbox, turboshaft engine and above listed additional components) would weigh 1.3 times the sum of the rotor, gearbox and engine weight. This factor is based on a turboshaft engine weight of 0.167 lbs. per SHP (0.101 Kg per Kw).

Sample Weight Calculations:

Rotor:

Given: Diameter, D = 16 ft.

Max. operating horsepower to the Prop-Fan = 17,920

Calculate: $\frac{SHP}{D^2} = \frac{17,920}{(16)^2} = 70$

Rotor weight from Figure 1 is 2070 pounds or 940 kilograms.

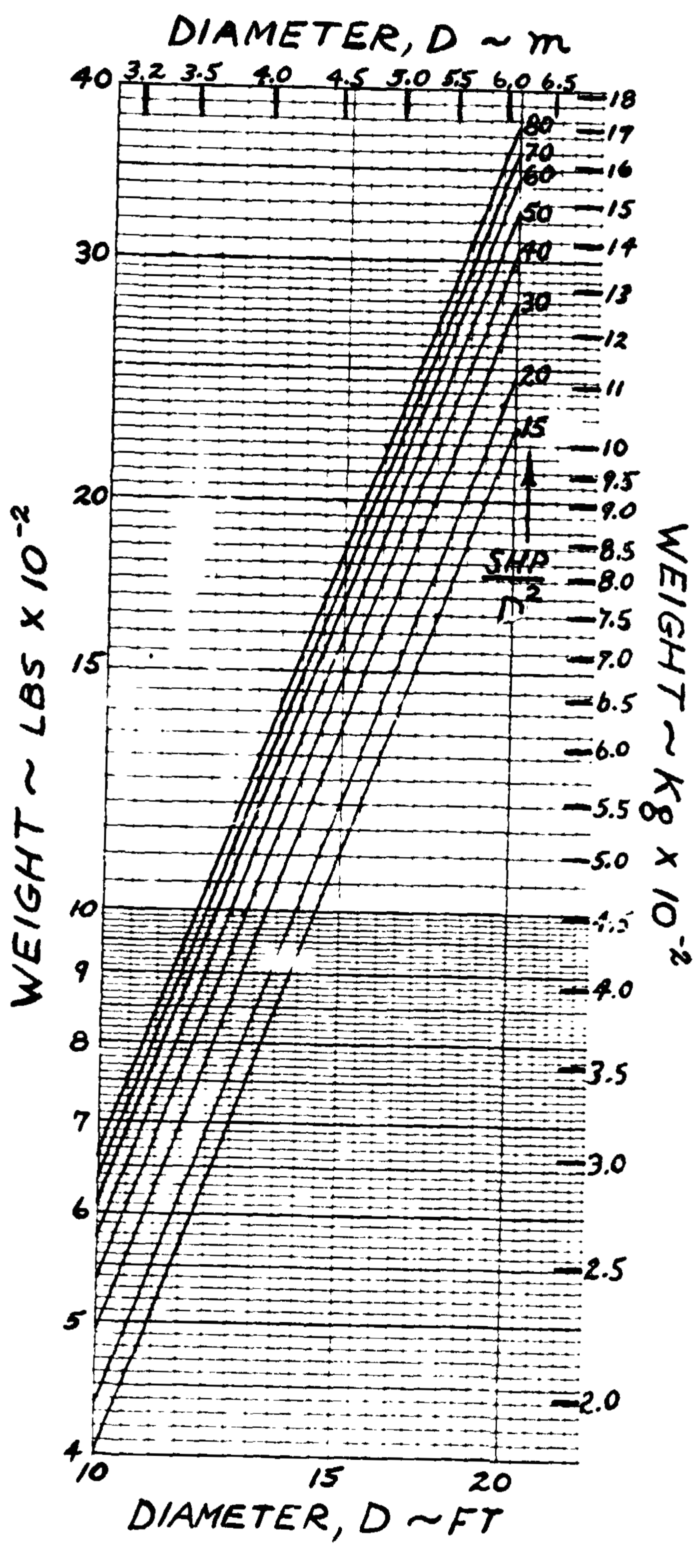
Gearbox:

Calculate: Max. output torque = 4.125 (SHP)(D)

Torque = (4.125)(17,920)(16) = 1.1827×10^6 in-lbs.

Gearbox weight from Figure 2 is 1450 pounds or 658 kilograms.

Note: The above torque equation is based on a tip speed of 800 ft/sec. Modify the torque by 800/TS for other tip speeds.



NOTES:

- WEIGHT INCLUDES:
  10 BLADES
  DISK W/O TAILSHAFT
  PITCH CHANGE SYSTEM
  SPINNER
- TIP SPEED, $TS = 800 \frac{ft}{sec}$ OR $244 \frac{m}{sec}$
- WEIGHT AT OTHER VALUES OF TS, WT_{TS}:
  $$WT_{TS} = WT_{800} \left[\frac{TS}{800}\right]^{0.3}$$
  WHERE:
  WT_{800} IS WEIGHT FROM THIS CURVE.
  TS IS TIP SPEED OTHER THAN 800 IN ft/sec.
- D IS ROTOR DIAMETER IN FEET OR METERS
- WEIGHT IS IN POUNDS OR KILOGRAMS
- $\frac{SHP}{D^2}$ IS IN $\frac{HP}{FT^2}$
  $$1 \frac{HP}{FT^2} = 8.027 \frac{KILOWATT}{METER^2}$$

FIGURE 1. ROTOR WEIGHT vs. DIAMETER FOR 10 BLADES

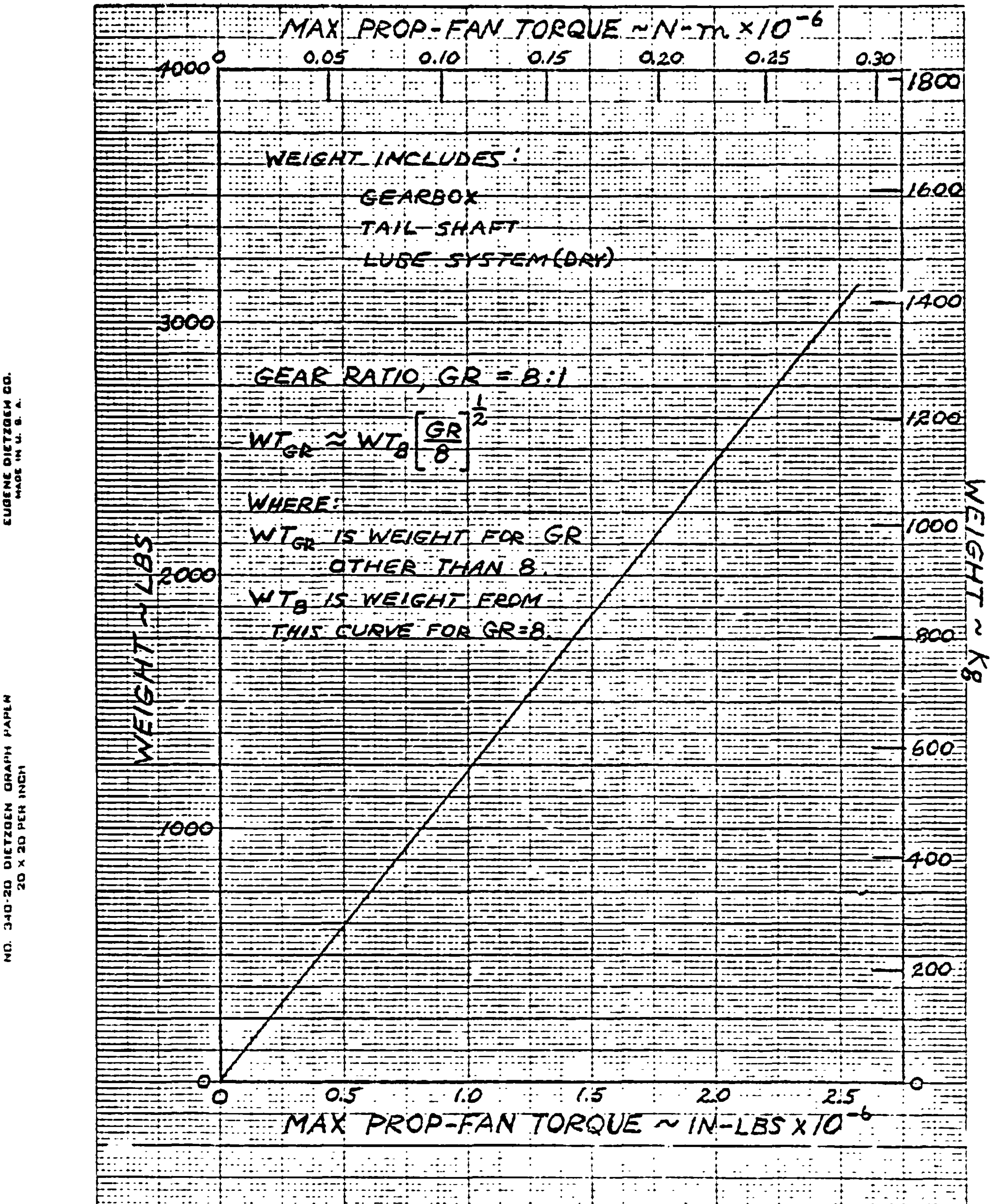


FIGURE 2. GEARBOX WEIGHT vs. PROP-FAN TORQUE

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SP20A77

GUIDELINES FOR PROP-FAN INSTALLATIONS

October 31, 1977

GUIDELINES FOR PROP-FAN INSTALLATIONS

It is recommended that the attached installation guidelines be included in general parametric and preliminary design studies of Prop-Fan propulsion systems. Previous studies have shown that the selection of the most appropriate Prop-Fan configuration and power loading (SHP/D^2) has to include an assessment of Prop-Fan diameter and its impact on the aircraft design.

The following installation guidelines are attached:

- Prop-Fan tip-to-fuselage clearance (Figure 1)
- Prop-Fan tip-to-tip clearance (Figure 1)
- Prop-Fan tip-to-ground clearance (Figure 1)
- Prop-Fan nacelle aerodynamic shape (Figures 2 and 3)
- Minimum Prop-Fan nacelle length and estimated loads (Figures 2 and 4)
- Minimum Prop-Fan whirl flutter stiffness (Figures 5 and 6)
- Prop-Fan vibration isolation criteria.

LIST OF SYMBOLS

Symbol	Definition	Units U.S.	Units S.I.*
d	Diameter of axisymmetric nacelle shape	ft	m
D	Prop-Fan diameter	ft	m
F	Blade tip-to-fuselage clearance	ft	m
H	Minimum blade tip-to-ground clearance	ft	m
K_T	Minimum effective torsional stiffness of wing/nacelle mount system (pitching)	$\frac{\text{in-lbs}}{\text{radian}}$	$\frac{\text{N-m}}{\text{radian}}$
ℓ	Distance of effective elastic center (torsional) of wing/nacelle mount system from the Prop-Fan plane of rotation	ft	m
L	Distance from the wing 1/4 chord station to the Prop-Fan plane of rotation	ft	m
M	Horizontal (yaw) moment at the Prop-Fan plane of rotation	in-lbs	N-m
M_N	Maximum aircraft Mach number		
n	Number of blades		
S_i	Vibration sensitivity, inboard nacelle	mils DA	
S_o	Vibration sensitivity, outboard nacelle	mils DA	
T	Minimum blade tip-to-tip clearance	ft	m
V	Vertical force at the Prop-Fan plane of rotation	lbs	N
Λ	Wing leading edge sweep angle	deg	deg
Φ	First-order excitation factor		
Ψ_t	Angle between the wing zero-lift line and the Prop-Fan thrust line	deg	deg
GW	Aircraft gross weight	lbs	Kg

* S.I. refers to Standard International units

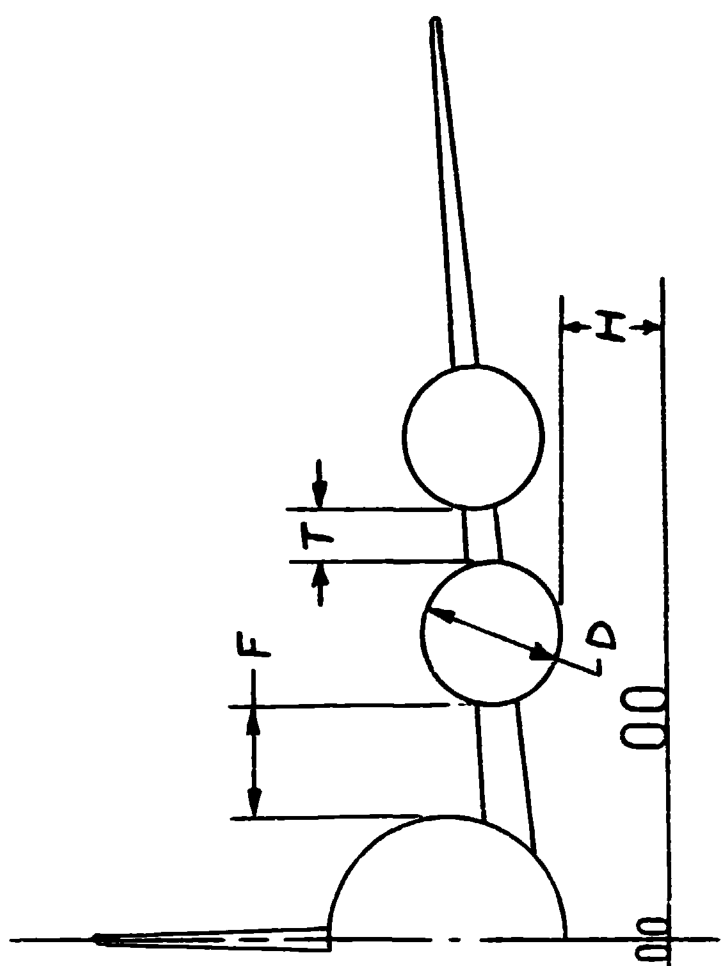


FIGURE 1. PROP-FAN SPACING REQUIREMENTS

<u>Formulas for Spacing</u>

$$H = \frac{(4.5)(10^{-3})(GW)(0.3 + Mn)}{D^2}$$

$$T = \left[\frac{0.05}{1 - 1.1\,(\tan\Lambda)^{1/2}}\right] D$$

for $\Lambda \le 35^\circ$

Recommended F = (0.8)D for acoustic purposes

Minimum F = (0.2)D for acceptable blade excitation loads

Note: The above equations are based on D, F, H and T being in feet and GW in lbs.

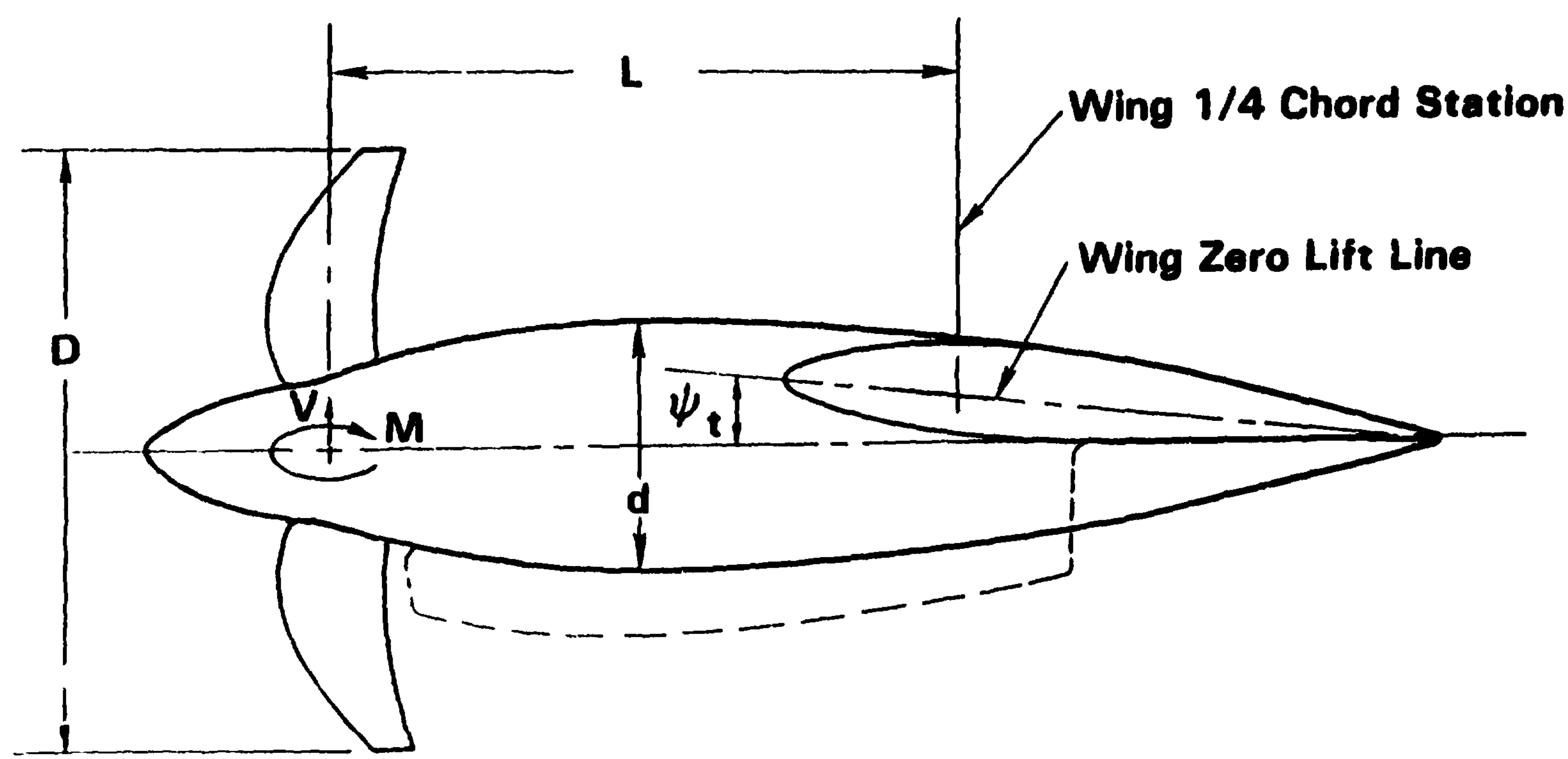


FIGURE 2. NACELLE INSTALLATION PARAMETERS

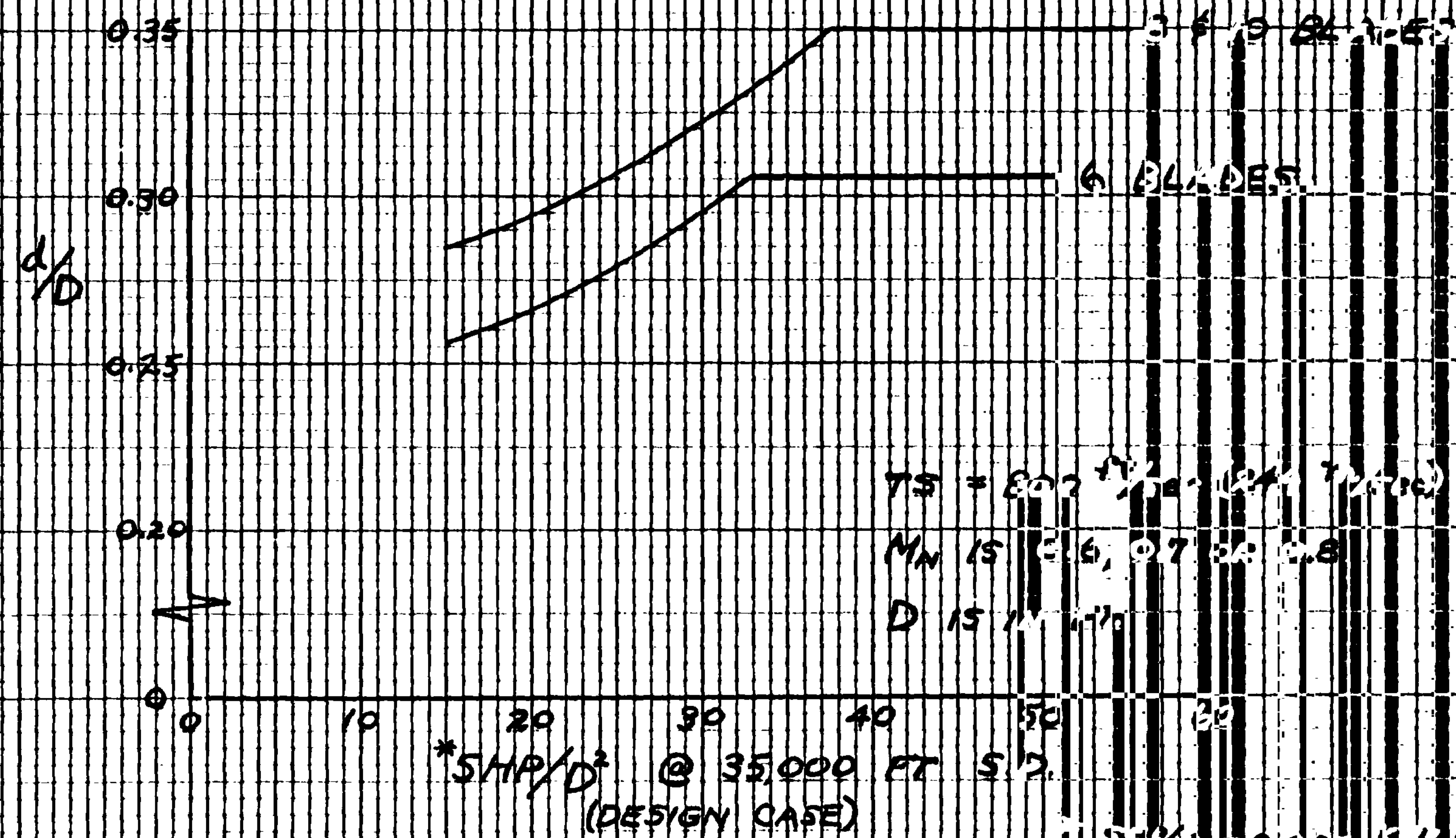


FIGURE 3. RECOMMENDED NACELLE/PROP-FAN DIAMETER RATIO

NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

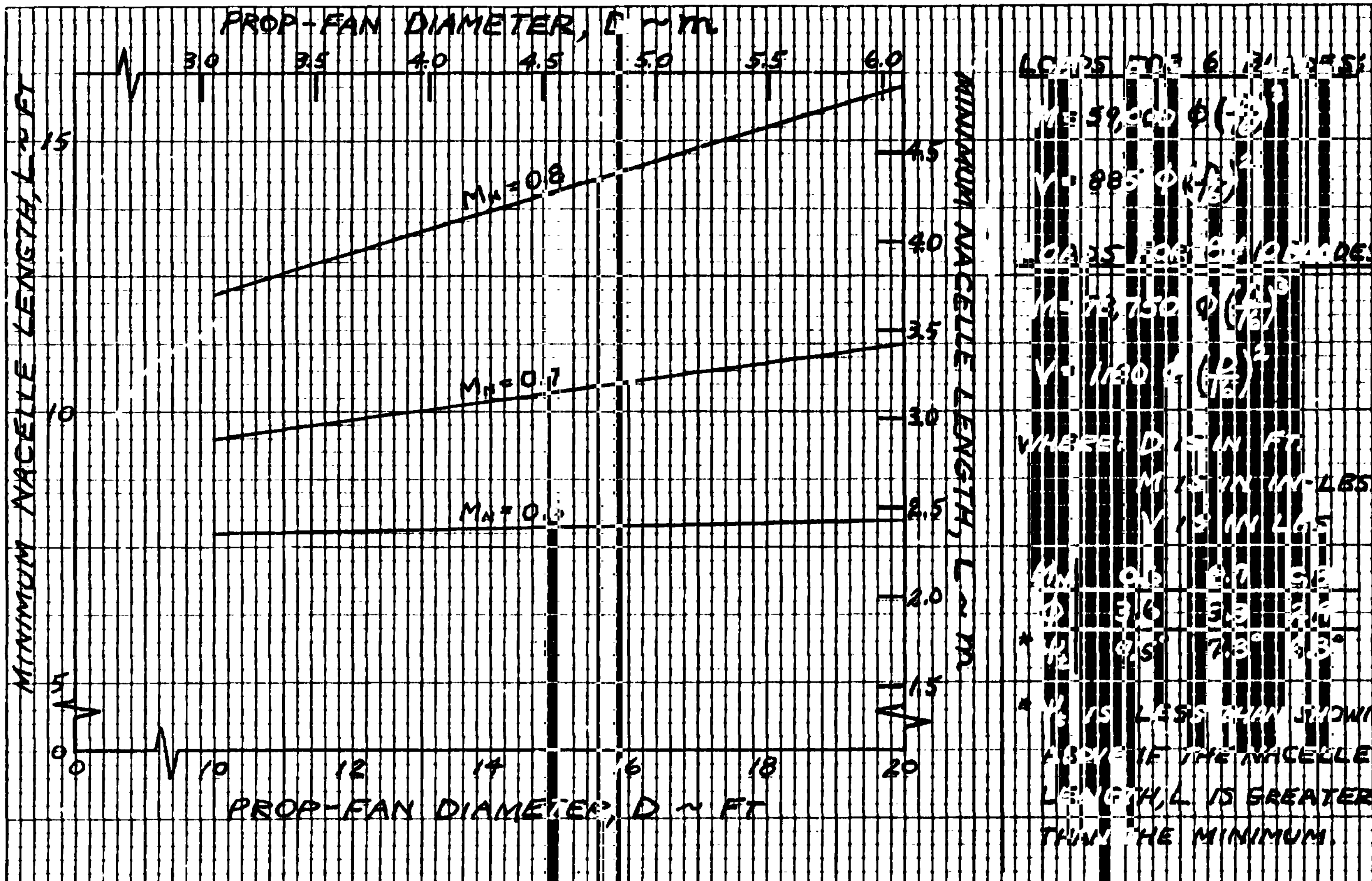


FIGURE 4. PROP-FAN NACELLE LENGTH AND LOADS

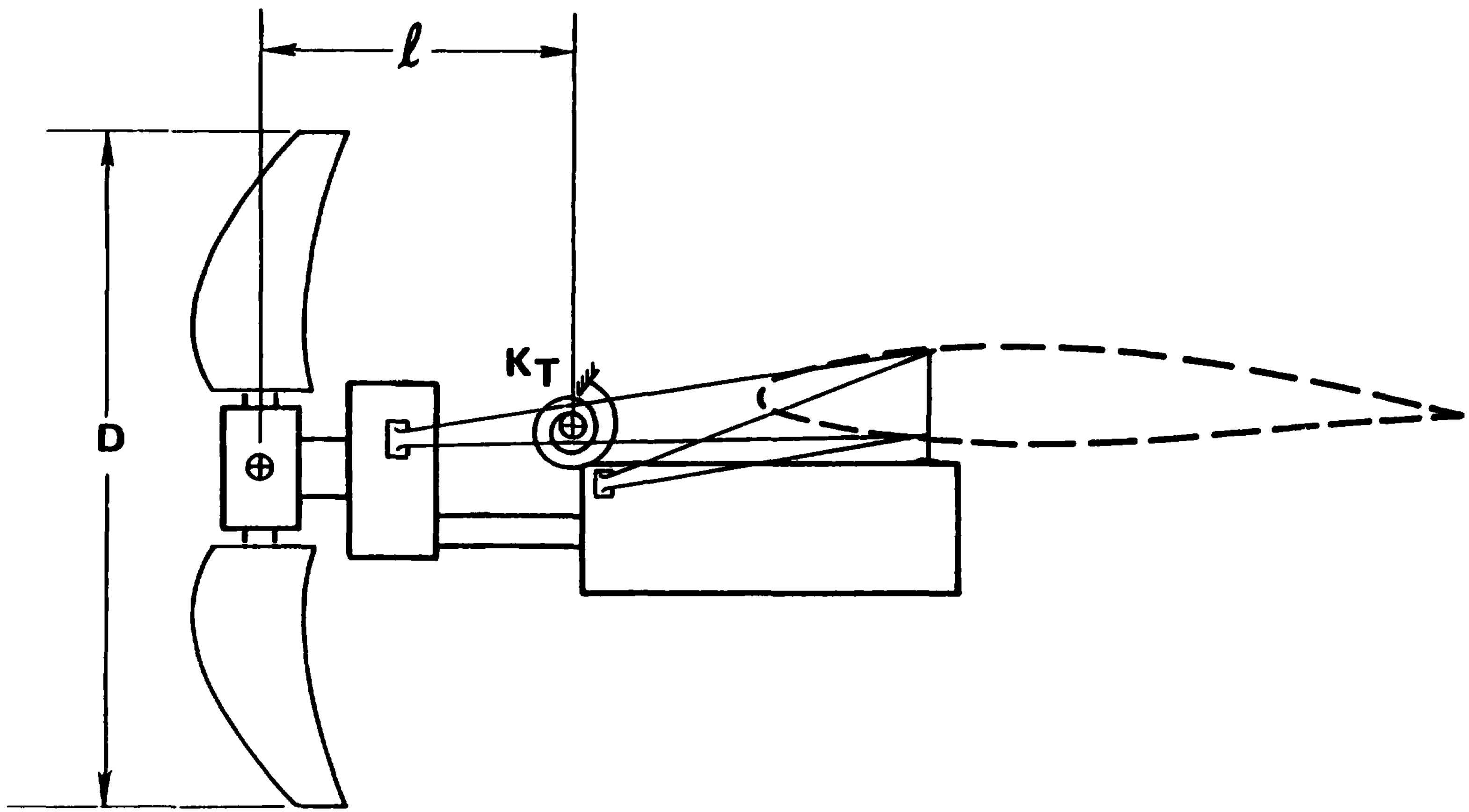
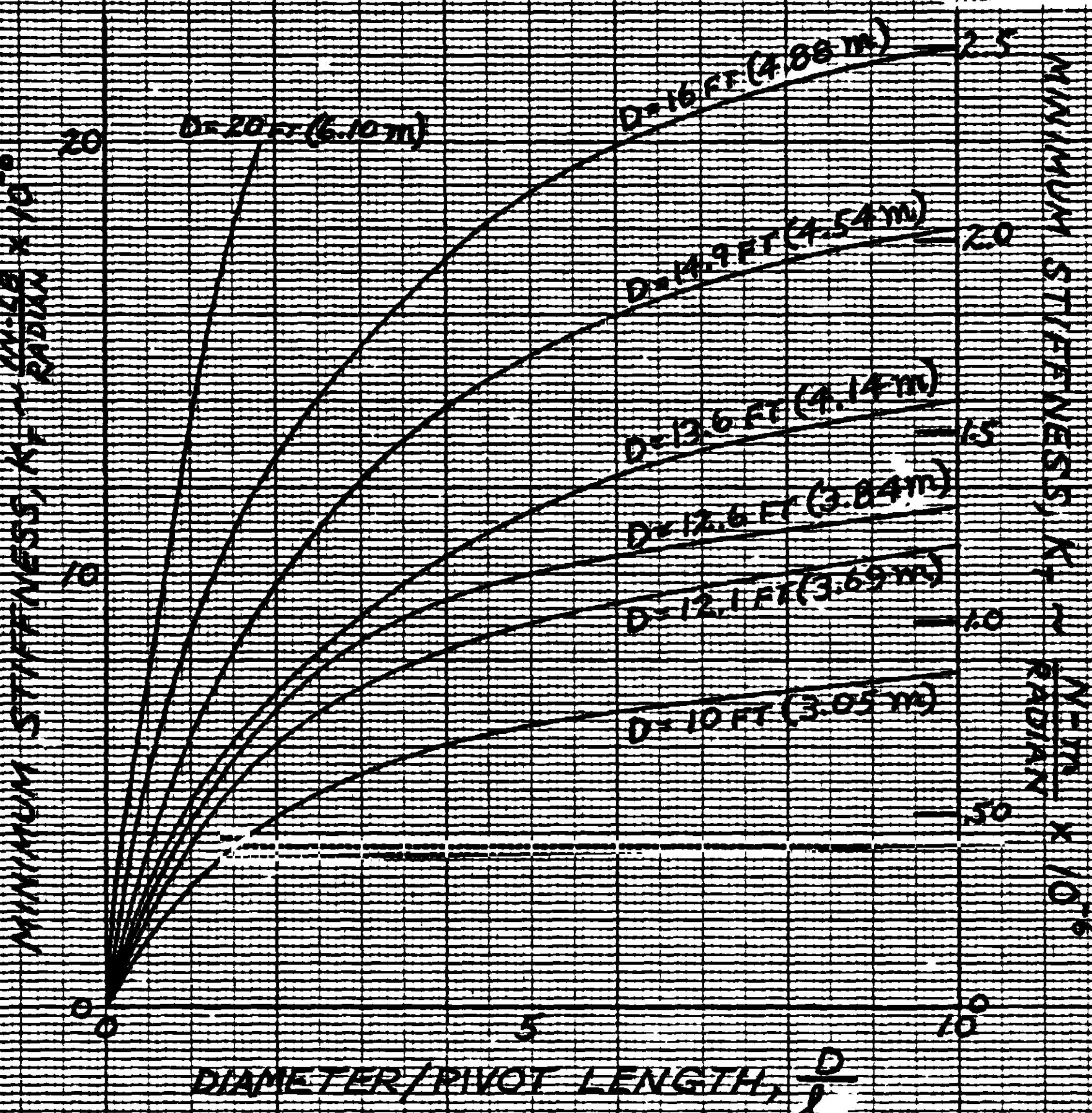


FIGURE 5. STIFFNESS DIAGRAM



NOTES:

- CURVE APPLIES TO 8 & 10 BLADES AT $M_N = 0.8$ AT 35,000 FT S.D.
- STIFFNESS REQUIRED FOR 6 BLADES WILL BE LESS THAN THE VALUES SHOWN ABOVE.
- FOR $M_N = 0.7$ OR 0.6, $K_T \cong K_{T(0.8)} \left[\frac{M_N}{0.8}\right]^{D/16}$ WHERE D IS IN FT.

FIGURE 6. STIFFNESS REQUIRED TO PREVENT WHIRL FLUTTER vs. DIAMETER/PIVOT LENGTH

SENSITIVITY REQUIREMENTS FOR PASSENGER COMFORT

$$(S_i^2 + S_o^2)^{0.5} \leq (0.000472 \text{ mils DA}) \left(\frac{16}{D}\right)^{0.85} \left(\frac{8}{n}\right)^{0.5}$$

Where S_i and S_o are vibration sensitivities in mils DA per lb. of Prop-Fan unbalance for inboard and outboard nacelles, respectively. The sensitivities are measured at the aircraft center of gravity and are established by the stiffness and isolation of the wing/nacelle structure and the Prop-Fan mounting. D is in feet.

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

SP03A78

PROP-FAN AND GEARBOX

RELIABILITY AND MAINTENANCE PREDICTIONS

February 28, 1978

Reliability and Maintainability

The reliability and maintainability data package contains information suitable for use in estimating total values for the Prop-Fan system and gearbox. Certain terms used in this package require definition to assure proper interpretation of their meaning:

- Commercial Environment is defined as operational use consisting of an average duty cycle of 1.25 hours per flight and a monthly utilization of 250 hours.

- Removal Rate is computed based on all removals including those not attributable to the hardware such as FOD and improper maintenance. In the case of the Prop-Fan, a removal is charged if any assembly or component such as a spinner, blade or pitch change actuator requires replacement as well as those few cases (less than 1% of the total) where the entire Prop-Fan assembly is removed. For the gearbox, all removals are of the entire gearbox module.

The following information is contained in this data package:

- Removal Rates.

  Reliability is affected only by the number of blades in the Prop-Fan configuration. For the gearbox, there is no variation. A table of values versus number of blades is presented for Prop-Fan. Values for the gearbox are also provided.

- Direct Maintenance Man Hours per Flight Hour and Parts Cost per Flight Hour.

  (1) Curves are presented for Prop-Fan maintenance manhours per 1000 unit flight hours as a function of Prop-Fan diameter and number of blades. Both Line and Shop maintenance actions are included.

  (2) A curve is presented for gearbox maintenance manhours per 1000 unit flight hours as a function of gearbox torque. Both Line and Shop maintenance actions are included.

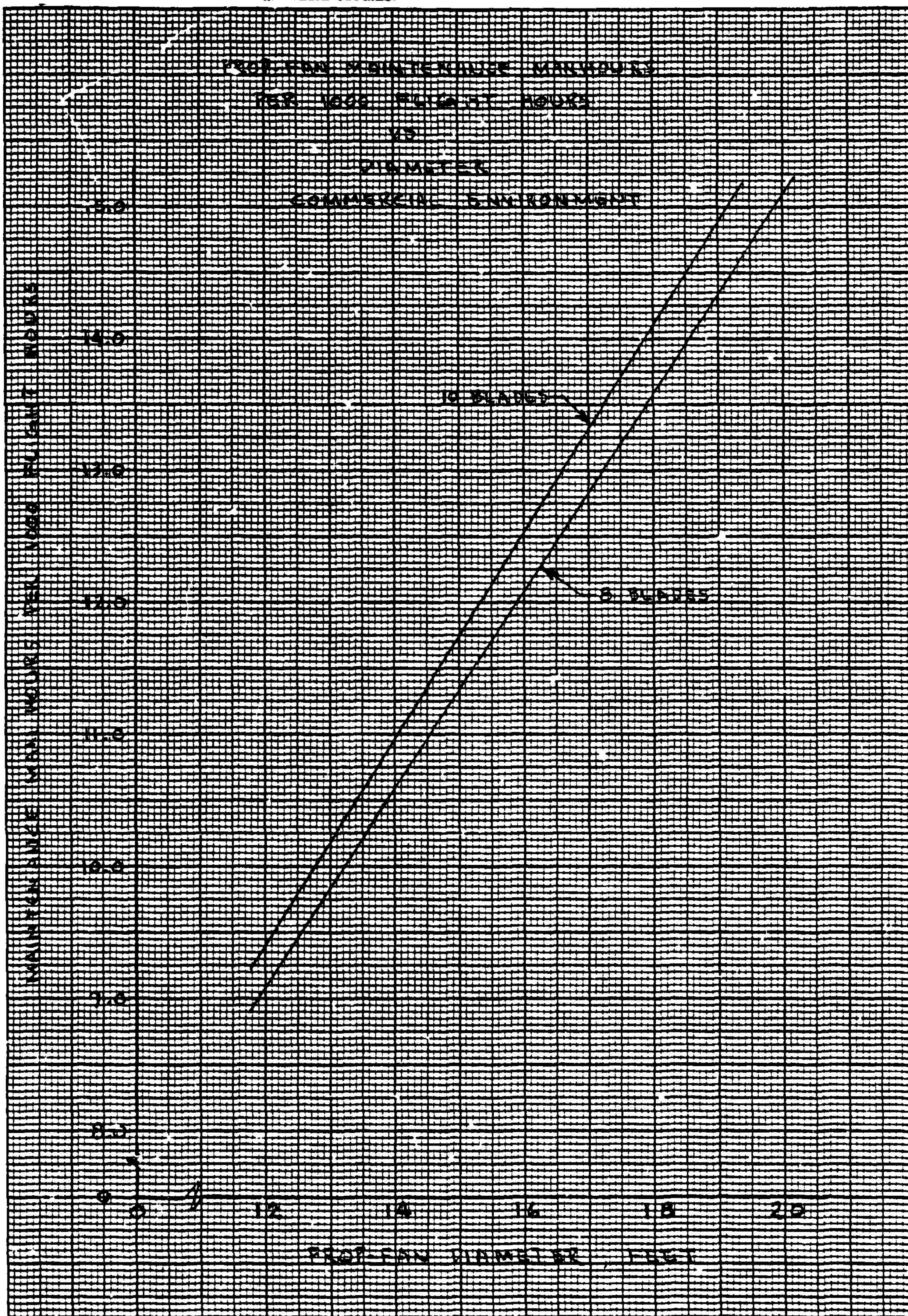
  (3) A plot indicating the Prop-Fan parts cost per flight hour as a function of diameter is presented. The values are for the case of 8 or 10 blades and a disc loading (SHP/D^2) of 75.

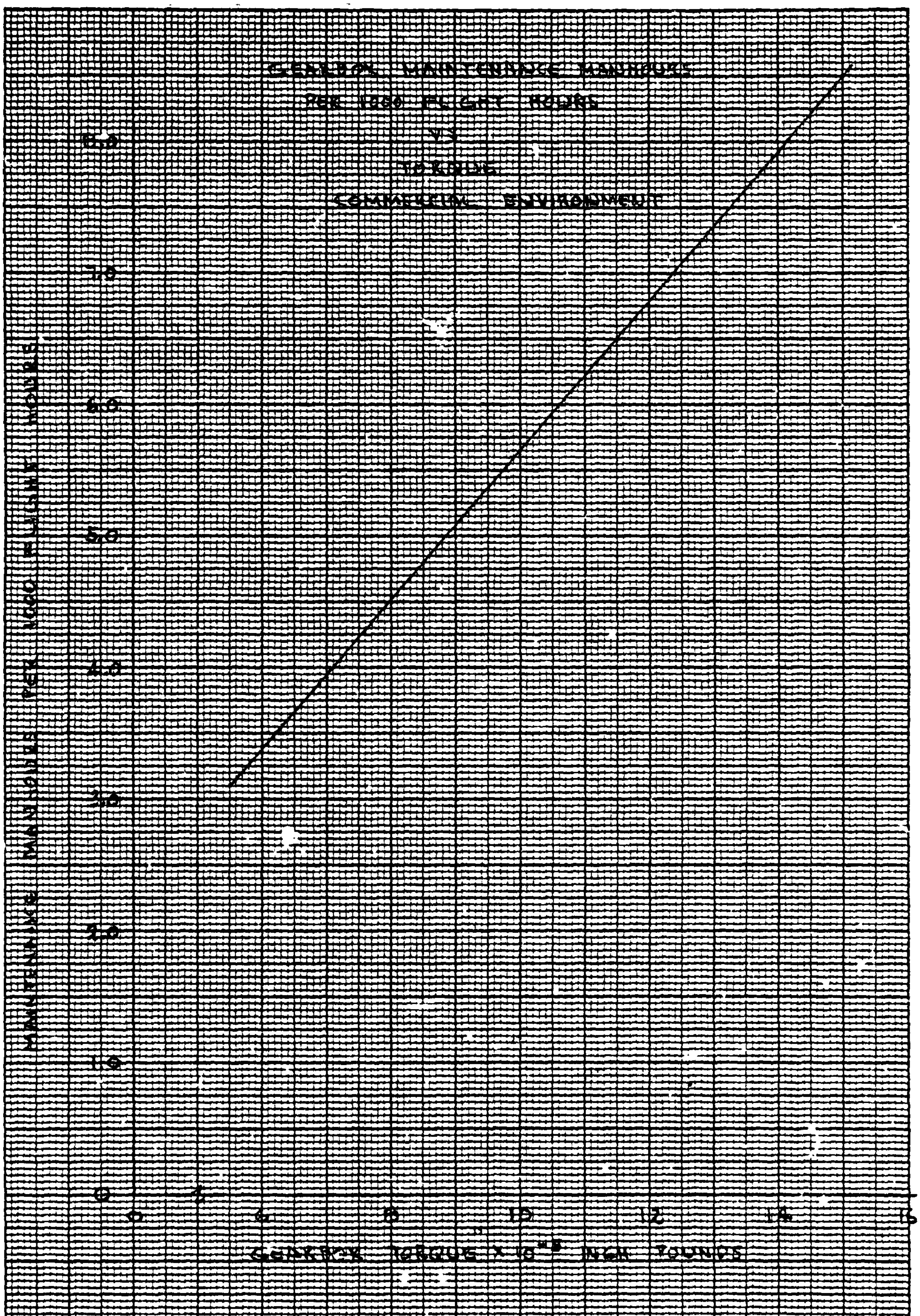
  (4) A plot of gearbox parts cost per flight hour as a function of gearbox torque is presented.

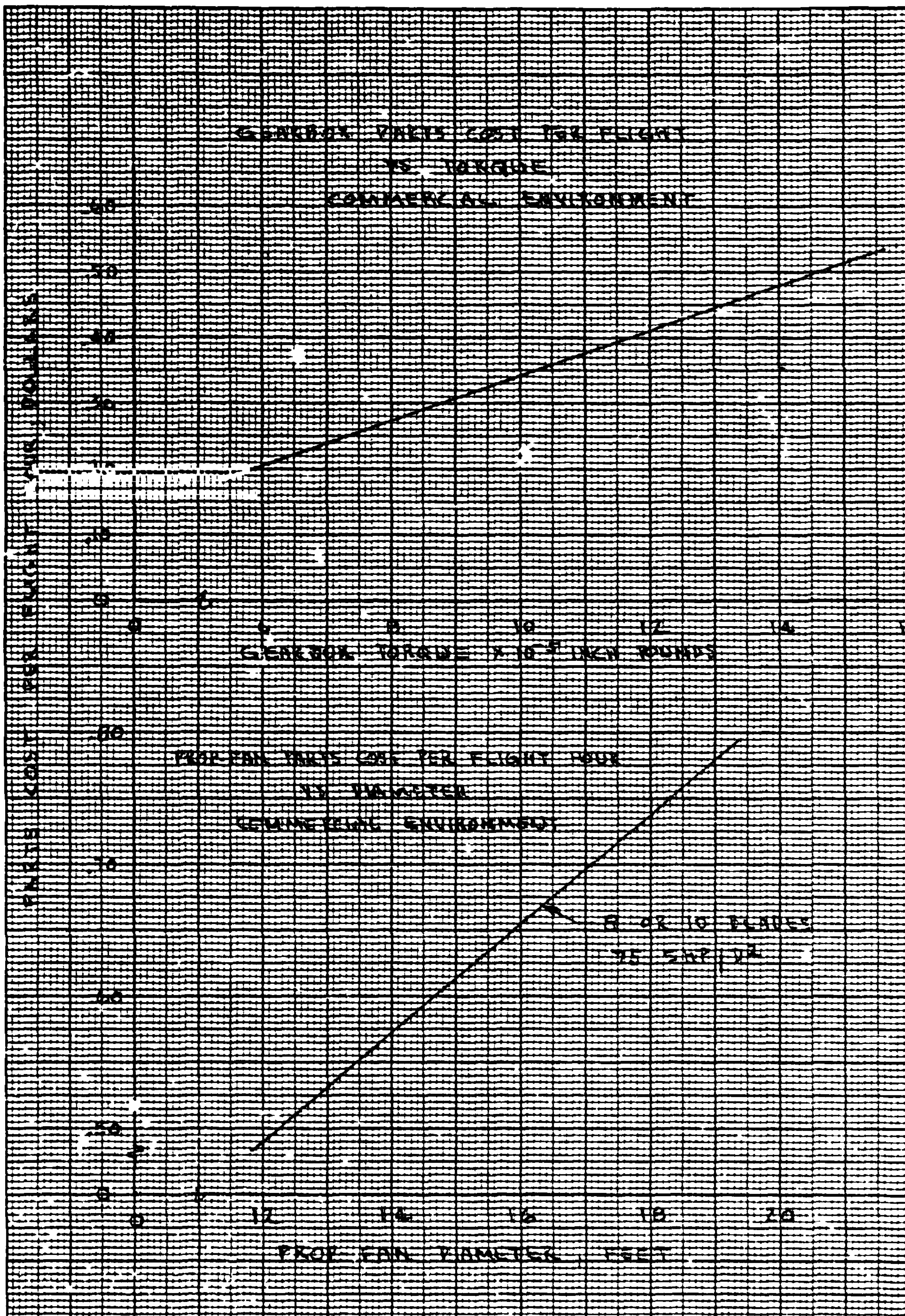
TABLE 1

Prop-Fan and Gearbox
Removal Rate
Commercial Environment

	Removal Rate (Removals/1000 FH)
8 Bladed Prop-Fan	0.356
10 Bladed Prop-Fan	0.364
Gearbox	0.040


PROP-FAN MAINTENANCE MANHOURS
PER 1000 FLIGHT HOURS
VS
DIAMETER
COMMERCIAL ENVIRONMENT
MAINTENANCE MAN HOURS PER 1000 FLIGHT HOURS
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
0
10 BLADES
8 BLADES
0
12
14
16
18
20
PROP-FAN DIAMETER, FEET


GEARBOX MAINTENANCE MANHOURS
PER 1000 FLIGHT HOURS
VS
TORQUE
COMMERCIAL ENVIRONMENT
MAINTENANCE MANHOURS PER 1000 FLIGHT HOURS
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
6
8
10
12
14
16
GEARBOX TORQUE X 10^{-3} INCH POUNDS


GEARBOX PARTS COST PER FLIGHT
VS TORQUE
COMMERCIAL ENVIRONMENT
.60
.50
.40
.30
.10
0
0
6
8
10
12
14
16
GEARBOX TORQUE x 10⁻⁵ INCH POUNDS
PARTS COST PER FLIGHT HOUR, DOLLARS
PROP FAN PARTS COST PER FLIGHT HOUR
VS DIAMETER
COMMERCIAL ENVIRONMENT
.80
.70
.60
.50
0
8 OR 10 BLADES
75 SHP/D²
0
12
14
16
18
20
PROP FAN DIAMETER, FEET